END
DATE
FILMED
6-78
DDC

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* Human Performance Tradeoff Curves for Use in the Design of Navy Systems		5. TYPE OF REPORT & PERIOD COVERED Final Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Arthur I. Siegel Wm. Rick Leahy J. Jay Wolf		8. CONTRACT OR GRANT NUMBER(s) N00024-76-C-6126
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Psychological Services, Inc. 404 East Lancaster Avenue Wayne, Pennsylvania 19087		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Department of the Navy		12. REPORT DATE April 1978
		13. NUMBER OF PAGES 48
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)*		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

This document has been approved for public release and sale;
its distribution is unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

DDC
RECEIVED
APR 28 1978
A

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

reliability	human factors	human performance
availability	system integration	system analysis
maintainability	tradeoffs	

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A series of human operator-system interdependencies is presented in the form of tradeoff curves. These curves were derived from computer simulation of a representative Navy mission. Performance at four work stations was simulated.

The resulting tradeoff curves present the relative impact of human oriented variables on system performance. Such curves possess merit as an aid to the

DD FORM 1473   EDITION OF 1 NOV 65 IS OBSOLETE
1 JAN 73

402 774

Item 20 (cont.)

equipment system designers who possess an interest in improving both overall system reliability, maintainability, and availability.

Human Performance Tradeoff Curves for Use

in the Design of Navy Systems

Arthur I. Siegel
Wm. Rick Leahy
J. Jay Wolf

prepared for

by

under

April 1978

ABSTRACT

A series of human operator-system interdependencies is presented in the form of tradeoff curves. These curves were derived from computer simulation of a representative Navy mission. Performance at four work stations was simulated.

The resulting tradeoff curves present the relative impact of human oriented variables on system performance. Such curves possess merit as an aid to the equipment system designers who possess an interest in improving both overall system reliability, maintainability, and availability

i

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (cont.)

CHAPTER I

INTRODUCTION

As automation and computer control of man-machine systems increases, there has been a parallel increase in the need for tradeoff considerations relative to the human element in complex systems. Computer modeling has grown in use and importance as a method for making tradeoff decisions. Computer models have been used for this purpose because there are few, if any, other techniques which can economically consider the wide variety of factors involved in such tradeoffs. While conceptual problems still remain with the development and validation of such models, the capability of simulation models to simulate a vast array of conditions and situations far outweighs the problems in their use. The economy, versatility, and practicality of such models has made their use the choice of planners of all types.

The basic reason for tradeoff considerations in system design is that design decisions usually possess multiple implications. A decision to increase the maximum altitude of an aircraft will affect, for example, its load carrying capability, its cruise speed, power considerations, and external configuration. In some cases, a minor modification of one factor may have a large impact on other factors. In other cases, a large modification may be made in one factor with only minimal effect on other factors. Knowledge of the relative effect of one factor on other factors is a necessary condition in order to make reasonable tradeoffs. Sometimes, due to the interaction of a number of different factors, the relative impact of one factor on other factors is much less or much more than one might anticipate.

Purpose of Present Work

The purpose of the present work was to develop a set of human performance oriented tradeoff curves for employment by design and development engineers. Such human performance tradeoff curves are believed to provide the engineer with a data base which he can employ when deriving a system or equipment design.

Sources of Tradeoff Data

Expert judgment is often employed to estimate tradeoff interactions. This source, often the only one available, has initial advantages in terms of low cost and immediacy of data. Other sources of tradeoff data are mathematical analysis, mockups, prototypes, and computer simulation. Mockups include physical analogues of all types ranging from bare physical analogues to dynamic mockups short of actual capability to perform equipment objectives. Prototypes, on the other hand, are actual test devices which are capable of performing at least some of the system objectives. Computer simulation involves logical modeling of relationships in such a form as to permit prediction of performance. Although the computer aspect is not a logical requirement of such sim-

ulation, it is a practical requirement given the usual complexity of the interaction of variables. In one sense computer simulation is an advanced form of mathematical analysis. Both computer simulation and mathematical analysis involve numeric processing according to formal logic but computer simulation can consider the dynamic interaction of a greater number of variables than mathematical analysis. Moreover, computer simulation is better prepared to consider the stochastic processes common to everyday life than mathematical analysis.

Table 1 summarizes the relative utility of each source of tradeoff data with reference to six criteria. The first criterion is the number of variables which may be simultaneously varied. The number of variables which can be manipulated reflects the depth of the evaluation yielded by the method. The human can consider two or possibly three variables at a time. Higher order tradeoffs are best resolved on the basis of raw judgment as sets of two or three factor tradeoffs. Physical analogues provide increased capability but are limited by time, cost, and flexibility considerations. Mathematical analysis usually only considers a limited number of variables simultaneously. Computer simulation can consider an almost unlimited number of variables in combination. Moreover, once the simulation model is developed, such simulation is relatively inexpensive and the results can be obtained in a timely manner.

The reliability and dependability of tradeoffs derived from the various methods also differs. Reliability is defined here as agreement between various applications of a method and dependability is defined as predictive power for various use conditions. Expert judgment is low on reliability and dependability because humans differ in the weights which they assign to variables and in their ability to compound weights. Data based on mockups or on prototype evaluations can be quite reliable and dependable because such evaluations can be carefully controlled. Mathematical analyses can be considered to be highly replicable. Computer simulations are highly replicable but their dependability depends on the care taken during the development of such models, on input data availability, and on whether or not the simulation has been appropriately validated.

Human judgment is highly flexible. It is difficult to modify mockups and prototypes so that they may be tried in a wide variety of conditions and at various levels of each condition. On the other hand, both computer simulation and mathematical analysis lend themselves to a flexibility need. For computer simulation, simple input data modification is often the only requirement for "trying" the system under consideration under new conditions of use, with different manning, or with different capability.

Computer simulation was employed to derive the tradeoff curves presented in Chapter II of this report.

Computer Simulation Model Employed

The computer simulation model used to derive these tradeoff curves has been used in a wide variety of simulation contexts. Most recently, the model was used in a

Table 1

Comparison of Various Tradeoff Methods

Method	Number of Variables	Characteristic				
		Cost	Time	Reliability	Dependability	Flexibility
Expert Judgment	low	low	low	low	low	high
Mockups	moderate	low	moderate to low	moderate	moderate	low
Prototypes	moderate	moderate	moderate	high	high	low
Math Analysis	low	low	low	high	moderate	moderate
Computer Simulation	high	low	low	high	moderate	high

3

study of a proposed sonar system (Leahy, Siegel, and Lamb, 1976). This model places emphasis on the human side of the simulation. However, equipment aspects are included.

The model is of the stochastic computer simulation nature and can simulate the performance of as many as 80 events or jobs per day. Teams of up to 20 persons can be simulated along with the repairs of a maximum of 20 different equipments and up to 10 classes of emergency situations. The input to the model consists of personnel data, equipment data, event data, and parameter values.

The personnel input data consist of such items as:

1. number of men holding each rank (pay grade) and specialty (Navy rate)
2. body weight
3. standard deviation of body weight
4. average proficiency in primary and secondary specialty
5. average work pace
6. average stress tolerance threshold
7. average caloric intake
8. average aspiration level
9. average physical capability
10. average hours since last sleep (at start of mission)
11. average duration of incapacity (sickness)
12. minimum fatigue necessary for sleep
13. average short term power output
14. average man's physical capability after a full workday

The equipment input data consists of such items as:

1. equipment failure rate
2. average repair time
3. standard deviation of repair time
4. number of men required to repair by type
5. mental load
6. consumable use

The event input data consists of such items as:

1. mean duration
2. standard deviation of duration
3. relative essentiality (importance)
4. mental load
5. for each consumable, the rate of expenditure and the minimum amount necessary to perform task
6. energy demands
7. hazard encountered in task performance
8. number and type of personnel required

Parameters consist of such items as:

1. initial value of each consumable
2. number of iterations
3. workday length
4. average crew pace
5. indicators for output recording options

Manipulation of the input data takes place in five major model segments. The first of these is crew formation. After each crew member is assigned, according to certain rules, to one of four command echelons (officer, senior petty officer, junior petty officer, or unrated), appropriate input variables are manipulated stochastically so as to generate a set of characteristics (e.g., competency, work proficiency, aspiration level, working pace, etc.) for each crew member. Accordingly, a unique crew is generated for each iteration or "cruise." This allows for simulation of the variance normally found across crews.

Next, the model uses a MTBF (mean time between failure) estimate in order to determine which, if any, equipment failures will occur this day. The failure determination is based on the assumption that the number of failures encountered are poisson distributed. The actual time of each repair during a simulated cruise is stochastically determined such that an occurrence can interrupt, at any time, the sequence of the day's scheduled activities. A parallel logic is applied in the determination of whether or not any emergency(s) will occur on each simulated day.

The third major segment of the model involves personnel assignment. Prior to the initiation of each scheduled repair or emergency event, the personnel assigned to the watch involved and necessary for performing the tasks within the event are selected. A first determination is made of the required specialties. Personnel within the needed specialties who have already worked or would be required to work too much "overtime" are subsequently eliminated from consideration. The remaining eligible personnel within each specialty are then further sorted in order to determine who has worked least this shift (watch). In the event that there is an excess of available men, those men are selected whose physical capability best matches the physical requirements of the event. Further "ties" among eligible personnel are resolved by selecting the man (men) with the greatest competence in his (their) primary specialty. Alternatively, by input specification that the event is for a training purpose, the simulation will select men on the basis of competence in their secondary specialty.

In the event that an insufficient number of men is available to perform the event, the computer selects watch members who are crosstrained in the needed specialties to fill the stations not yet fully manned. If there is still an insufficient number of men available, the computer simulates the task as being performed with an inadequate number of personnel and the number of unmanned stations is calculated.

Once the work group for an event is "assembled," the role of group leader is assigned to the highest ranking member or to the most competent among equal highest ranking members working on the task.

5

The fourth model segment involves the simulation of actual event performance. The first step in this segment involves a determination of whether the event should be ignored because: it is below the essentiality threshold, the consumables are below the levels required for event performance, an inadequate amount of time is available for event completion, or no personnel with the required skill are available. In no case is a repair or an emergency event skipped.

The model assigns an appropriate event start time after it has determined that performance of the event is to be simulated and the work team has been selected. The event start time is assigned within the following restrictions: the time the assigned men became available, the time of completion of any specified event which has to be completed prior to the present event, and the earliest possible start time that was specified in the input data base.

The actual performance time is determined as a function of stochastic manipulation of the initial input data mean and standard deviation of event performance time, as well as the group working pace and the stress on the work group. The group pace is considered to be independent of the group's physical capability which, in turn, is calculated as a function of the following characteristics of each crew member: (1) current fatigue level, (2) physical capability, (3) prior overexertion during an event performance, and (4) time since last slept (time fatigue). The stress is determined as a function of the amount of time available, the average performance time for event completion, and the mental load involved in task performance.

Two additional group derived variables, competence and aspiration, in conjunction with group stress and group physical capability, determine the group performance adequacy. Aspiration is considered to be a function of goal descrepancy and stress and affects event performance time through working pace.

A success or failure determination is made for the task by using as a success criterion the leader's expectation of performance quality. This is quantified by comparing the calculated performance adequacy with the leader's aspiration weighted by an expectation constant provided by input.

After event completion, the personnel records are updated in order to account for changes resulting from the work done. In addition, other bookkeeping is performed to record the various aspects of the event for a later summary. Subsequent to the performance of each event, a check is made to determine if the day has ended and, if not, the next event is selected and processed in the same manner. At the day's completion, a check is made to determine if this was the last day of the mission. If not, end-of-day performance summaries are compiled, and the next day's schedule is generated. At mission end, a final tabulation across all relevant variables, events, and personnel is made.

A brief summary of the five main model segments is presented in Table 2.

6

Table 2

Summary of the Five Main Model Segments

1. crew formation   identification of each crew member and assignment
                                    of specific capabilities and characteristics to
                                    each crew member

2. daily schedule generation   preparation of itemized events to be completed
                                    on each day of the mission

3. personnel assignment   selection of individual men to accomplish the
                                    work of each event

4. event simulation   calculation of conditions existing during each
                                    event and the determination of how well and how
                                    quickly the assigned men accomplish the work
                                    which constitutes the event

5. personnel update   modification of the values of psychosocial and
                                    other variables as a result of group and in-
                                    dividual performance during the event

This model has received prior validation outside of the present program. Examples of prior validational studies are found in Siegel, Wolf, & Cosentino (1971), Siegel, Lautman, & Wolf (1972), and Siegel, Leahy, & Wiesen (1977). In all of these studies, the model's output was compared with actual data and acceptable conformity was evidenced.

A number of human, equipment, and system (combined human and equipment) metrics are also generated by the model. These are of particular interest to the system designer and are defined and summarized in Table 3.

7

Table 3

Systems Metrics Yielded by Model

HUMAN RELIABILITY $= \left(1 - \dfrac{\text{No. of failures}}{\text{Total attempts}}\right)$

HUMAN AVAILABILITY $= \left(1 - \dfrac{\text{Time lost or unmanned hours}}{\text{Total mission manhours}}\right)$

HUMAN MTTR $= \left(\dfrac{\text{Total time of second try}}{\text{No. of second try}}\right)$

EQUIPMENT RELIABILITY $= \left(1 - \dfrac{\text{No. of failures during mission}}{\text{No. of iterations}}\right)$

EQUIPMENT AVAILABILITY $= \left(\dfrac{\text{Equipment up time}}{\text{Equipment up time + down time}}\right)$

EQUIPMENT MTBF $= \left(\dfrac{\Sigma \text{ times between failures}}{\text{No. of failures}}\right)$

EQUIPMENT MTTR $= \left(\dfrac{\text{Total EMTTR values over all iterations}}{\text{No. of iterations}}\right)$

SYSTEM RELIABILITY $= \left(1 - \dfrac{\text{No. of equipment failures + No. of second try successes}}{\text{No. of iterations}}\right)$

SYSTEM AVAILABILITY $= \left(1 - \dfrac{\text{Equipment down time}}{\text{Mission time}} \left(\dfrac{\text{Unmanned hours}}{\text{Mission time}}\right)\right)$

SYSTEM MTTR $= \left(\dfrac{\Sigma \text{ time for repairs + } \Sigma \text{ time for second try successes}}{\text{No. of repairs + No. of second try successes}}\right)$

8

Mission Simulated

A representative mission was required to provide a basis for the tradeoff curves to be generated as the major product of the present work. To this end, a mission was synthesized which was believed to meet the following criteria:

Generalizability. A Navy mission without unique conditions which would cause mission specific output.

Verisimiltude. A mission with reasonable complexity, crew interaction, and work load. The tasks used could have been assigned natural names such as trouble shooting, calibration, repair/replacement, or equipment operation. However, by leaving them undefined, the similarity to many different Navy situations is enhanced.

Crewman Dependency. A mission which emphasizes human performance. Therefore, equipment dependencies (such as warm-up time and other fixed, rigidly predictable from other sources, equipment factors) were minimized and crewman functions were emphasized.

The decision was reached to simulate human performance at each of four work stations. Each station is manned by one crew member. The stations are continuously manned. The duration of each watch is four hours.

This mission was generated from a list of random numbers with restrictions. The restrictions were used to meet the criteria described above. Four task durations were used--5, 10, 20, and 40 minutes. Sufficient tasks were assigned to each work station to cause approximately three quarters of each four hour shift to be occupied. This nominal time usage was based on average performance time for each task. The remaining time was left for accommodating equipment failures and emergencies, which are generated by the model, and to allow for time to complete task repetitions because of task failure by the crewmen.

Figures 1, 2, and 3 present time line charts of the tasks in each watch. The numbers shown inside the time line bars of Figures 1, 2, and 3 indicate the sequenced task numbers. Sequenced task numbers are unique to each scheduled task within a simulation.

Approximately 10 percent of the tasks were interdependent between work stations. These interdependencies are shown in the timeline by an interconnecting, dashed line. The tasks shown at the tails of the dashed arrows may not be started until the tasks at the heads of the arrows have been completed. For example, sequenced task number 10, which is to be performed at station one, cannot begin until sequenced task number 33 is completed at station four. Prerequisite tasks were selected randomly with the restriction that there were four prerequisite tasks per shift.
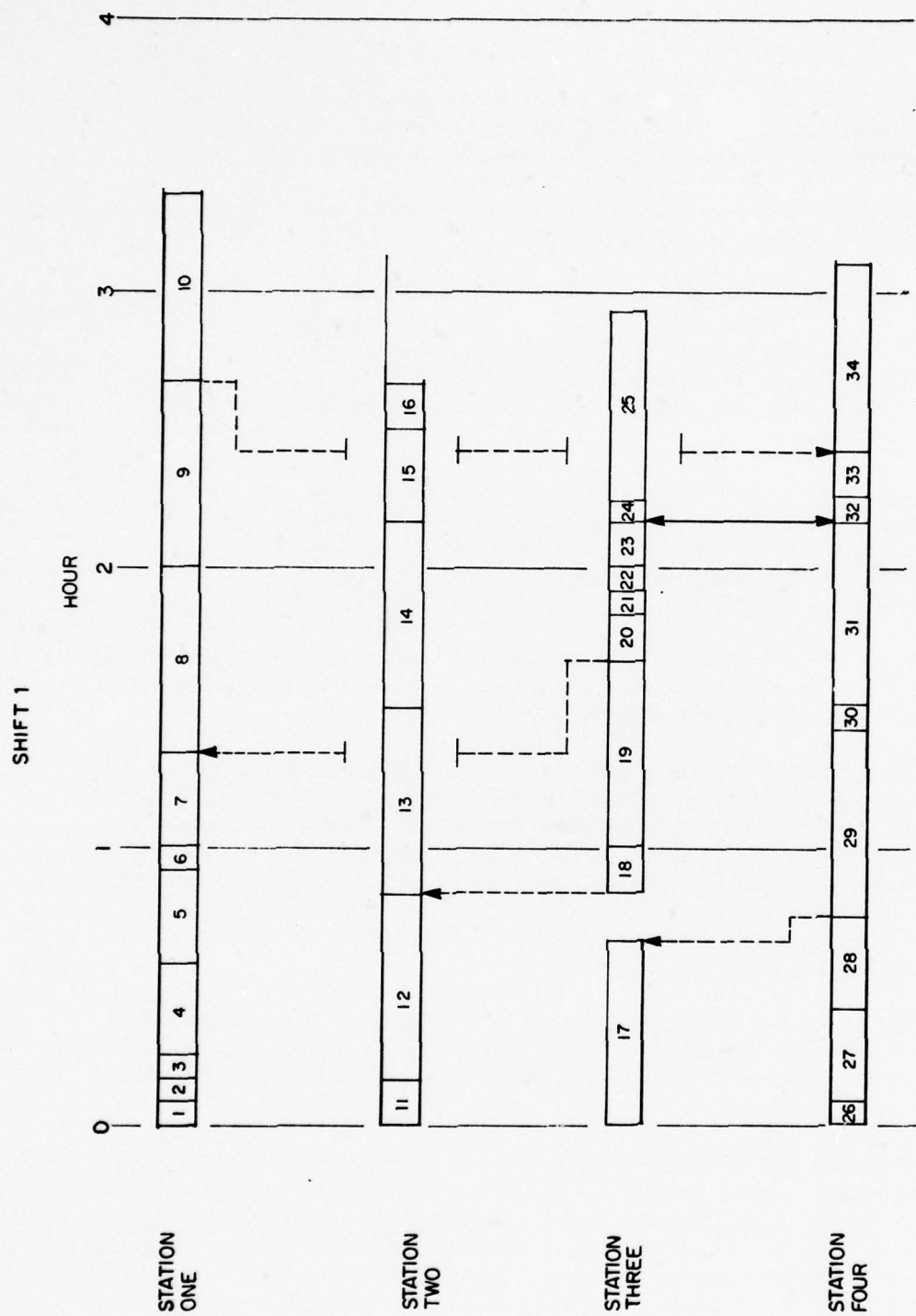
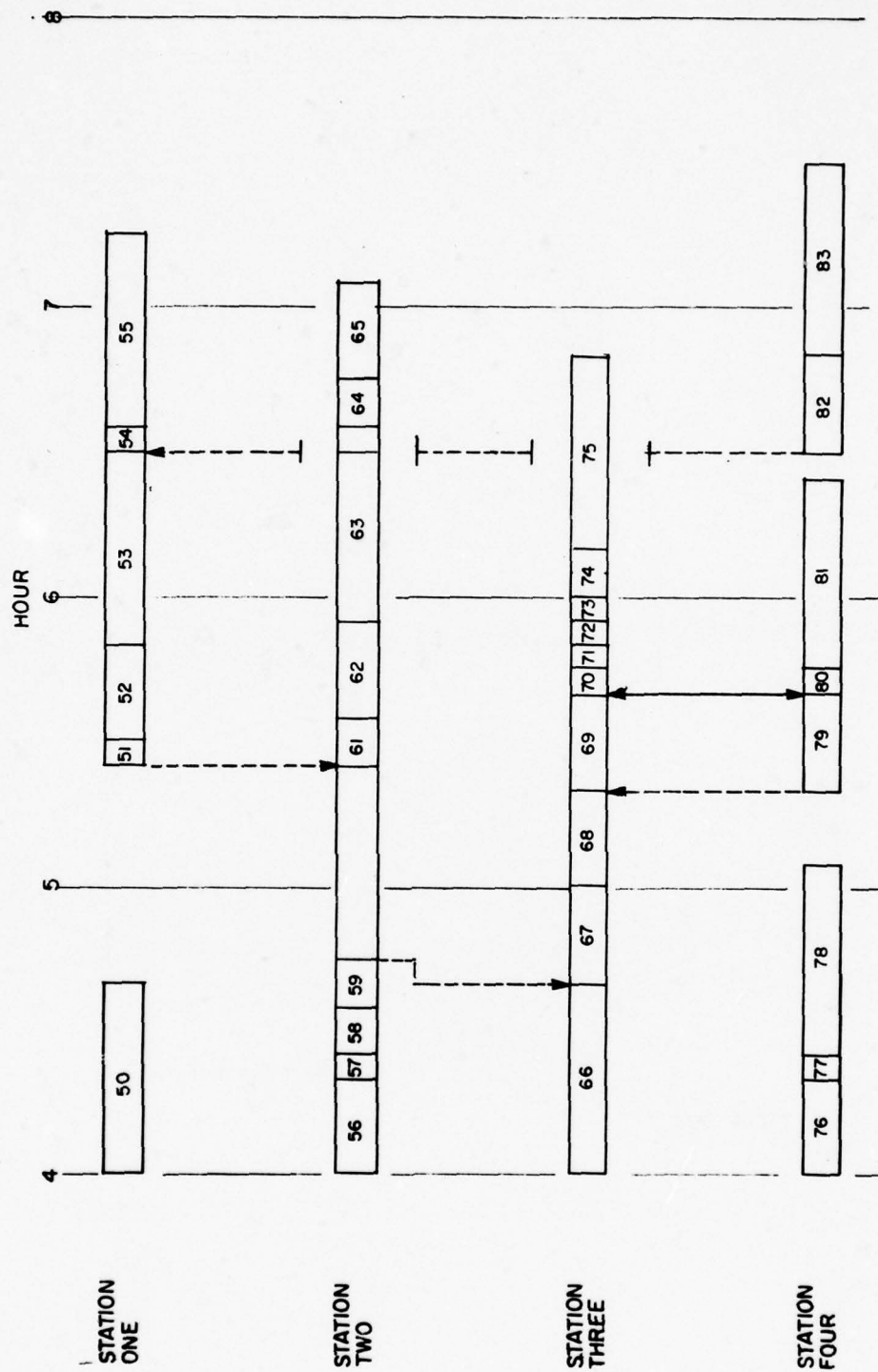FIGURE 1. TIME LINE CHART OF WATCH 1.

10

SHIFT 2

HOUR

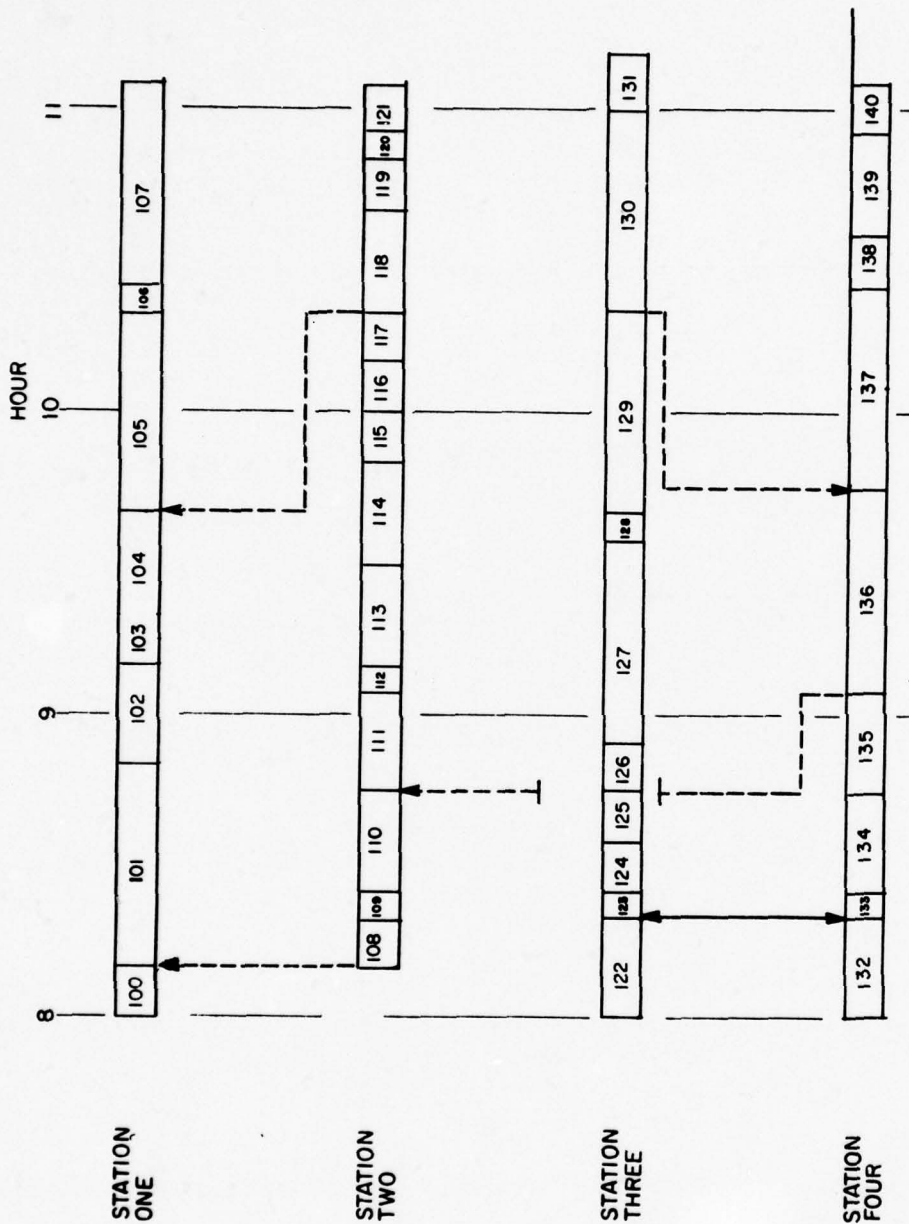FIGURE 2. TIME LINE CHART OF WATCH 2.

11

FIGURE 3. TIME LINE CHART OF WATCH 3.

Another type of task interdependency is shown by the solid line arrows. The solid line arrows with arrow heads at both ends connect tasks which must be performed simultaneously, i.e., joint tasks. In watch 1, task 32 at station four is performed jointly with task number 24 at station three. One joint task occurs during each of the three watches.

The sequenced tasks are also controlled within the simulation model by the time interval in which they must be performed. In the present simulation, sequenced tasks were constrained to the watch in which they were scheduled.

Consumable shortages could serve to make a simulation unique. In order to make the results of these tradeoff simulations as generally applicable as possible, consumable expenditure was not simulated. We do not minimize the importance of consumables in a mission, but this variable can often be considered independently.

A 12 hour simulated time interval was selected. This time duration was previously found to be sufficient for providing meaningful simulation results. The simulation has an upper limit on the total number of tasks which can be considered during a simulation and with longer time periods each task must be, on the average, longer and therefore the degree of granularity is decreased.

One unit of equipment was assigned within the scenario to each work station. Failure rates were assigned to each equipment unit so as to represent a range of failure rates. A mean input time to repair (MTTR) of one-half hour was assigned for all repairs.

Simulation Runs Completed

Simulation runs were completed in which a number of human oriented variables were manipulated. The eight human oriented variables manipulated over various simulation runs and the levels of these variables are summarized in Table 4. The upper and lower limits for each variable are believed to represent plus or minus two standard deviations around the respective mean.

The two and the six hour watch lengths, respectively, place a heavy and a light work load on the simulated operation. Similarly, the three and the five man personnel availabilities (men per watch) respectively impose an overload and an underload situation.

A total of 23 simulation runs was completed. The parameter values for each run are shown in Table 5. Only one input parameter was varied in each run. Other than the variable being manipulated during the run, the input parameters were those used in the baseline run.

13

Table 4

Summary of Independent Variables Manipulated and Levels Included in Various Simulation Runs

Variable	Low		Mean		High
Aspiration	.80		.90		1.00
Leader's Expectation	.85		.90		.95
Men per Shift	1	3	5	7	9
Mental Load	3		4		5
Primary Competence	.55	.65	.75	.85	.95
Pace	1.30	1.15	1.00	.85	.70
Secondary Competence	.55		.75		.90
Watch Length	2		4		6

Table 5

Simulation Runs Performed

Run	Primary Competence			Secondary Competence			PACE	Shift Length	Mental Load	Men per Shift	Aspiration	Leader's Expect.
	Full*	Min	Un	Full	Min	Un						
1. Baseline	.75	.25	.00	.25	.50	.25	1.00	4	5	4	.90	.90
2. Prim. Comp.	.95	.05	.00	.25	.50	.25	1.00	4	5	4	.90	.90
3	.85	.15	.00	.25	.50	.25	1.00	4	5	4	.90	.90
4	.65	.35	.00	.25	.50	.25	1.00	4	5	4	.90	.90
5	.55	.45	.00	.25	.50	.25	1.00	4	5	4	.90	.90
6. Men/Shift	.75	.25	.00	.25	.50	.25	1.00	4	5	3	.90	.90
7	.75	.25	.00	.25	.50	.25	1.00	4	5	5	.90	.90
8. PACE	.75	.25	.00	.25	.50	.25	0.70	4	5	4	.90	.90
9	.75	.25	.00	.25	.50	.25	0.85	4	5	4	.90	.90
10	.75	.25	.00	.25	.50	.25	1.15	4	5	4	.90	.90
11	.75	.25	.00	.25	.50	.25	1.30	4	5	4	.90	.90
12. Shift Length	.75	.25	.00	.25	.50	.25	1.00	2	5	4	.90	.90
13	.75	.25	.00	.25	.50	.25	1.00	6	5	4	.90	.90
14. Second. Comp.	.75	.25	.00	.90	.10	.00	1.00	4	5	4	.90	.90
15	.75	.25	.00	.55	.45	.00	1.00	4	5	4	.90	.90
16. Mental Load	.75	.25	.00	.25	.50	.25	1.00	4	1	4	.90	.90
17	.75	.25	.00	.25	.50	.25	1.00	4	3	4	.90	.90
18	.75	.25	.00	.25	.50	.25	1.00	4	7	4	.90	.90
19	.75	.25	.00	.25	.50	.25	1.00	4	9	4	.90	.90
20. Level Aspiration	.75	.25	.00	.25	.50	.25	1.00	4	5	4	.80	.90
21	.75	.25	.00	.25	.50	.25	1.00	4	5	4	1.00	.90
22. Leader's Expect.	.75	.25	.00	.25	.50	.25	1.00	4	5	4	.90	.85
23	.75	.25	.00	.25	.50	.25	1.00	4	5	4	.90	.95

Full = % fully qualified
Min = % minimally qualified
Un = % unqualified

14

CHAPTER II

TRADEOFF CURVES

Overall

On the basis of the results of the simulation runs described in Chapter I, a number of tradeoff curves was derived. These curves describe the relationships between selected independent variables and an appropriate dependent variable. The independent variables include conditions which are under the control of a system designer to some degree, e.g., crew mental load or manning level. The effect of systematic variation of the independent variables is described in terms of the dependent variables or measures of system performance. These dependent variables are:

I. Mean Hours Worked
II. Percentage of Success
III. Unmanned Station Hours
IV. Percentage of Tasks Ignored
V. System Reliability
VI. System Availability
VII. System MTTR
VIII. Human Reliability
IX. Human Availability
X. Human MTTR
XI. Maximum Stress
XII. Hazard
XIII. Human Availability and Manpower Utilization Interaction

Within each dependent variable section, the effects of selected independent variables are shown. The independent variables in each section were selected on the basis of their logical association with the dependent variables. Only relationships with reasonably systematic effects, as indicated by the simulation model, are shown. Relationships which seemed to be primarily due to stochastic effects are not included.

Goodness of Fit

Each tradeoff curve is based on a least square fit. The equations used for this calculation were:

$$\text{Slope} = m = \frac{\frac{\Sigma x \Sigma y}{n} - \Sigma xy}{\frac{(\Sigma x)^2}{n} - \Sigma x^2}$$

15

$$\text{Intercept} = b = \frac{\Sigma y - m\Sigma x}{n}$$

y = dependent variable
x = independent variable
n = number of data points

The resulting equation is in the form:

$$y' = mx + b$$

In most cases a linear best fit was preferred. In some cases an exponential fit was calculated. For calculation of the exponential curve fit, the equations employed were:

$$a = \exp\left[\frac{\Sigma \ln y_i}{n} - \frac{b\Sigma x_i}{n}\right]$$

$$b = \frac{\Sigma x_i \ln y_i - \dfrac{\Sigma x_i \Sigma \ln y_i}{n}}{\Sigma x_i^2 - \dfrac{(\Sigma x_i)^2}{n}}$$

The resulting equation is in the form:

$$y = ae^{bx}.$$

In a few cases a logarithmic best fit seemed most appropriate. In these cases, the following equations were used for calculating the best fit:

$$a = \frac{\Sigma y_i - b\Sigma \ln x_i}{n}$$

$$b = \frac{\Sigma y_i \ln x_i - \dfrac{\Sigma \ln x_i \Sigma y_i}{n}}{\Sigma (\ln x_i)^2 - \dfrac{\Sigma (\ln x_i)^2}{n}}$$

The resulting equation is in the form:

$$y = a + b\ln x.$$

16

Multiple Curves on the Same Axes

Independent variables which are graphed together were grouped on the basis of similarity of the variables involved.

I. Mean Hours Worked

This section presents the effects of five independent variables on the number of hours worked.

Hours worked represent the mean time worked by each crewman during a watch. The independent variables found most important to hours worked are presented in three graphs. The pairs of independent variables selected for display are:

        A. Primary Competence
           Secondary Competence

        B. Men Per Shift
           Shift Length

        C. Pace

The equations for these relationships are shown in Table 6.

Table 6

Equations for Variables Affecting Hours Worked

If Y represents mean hours worked and X
represents primary specialty competence
   then: $Y = -1.05X + 3.858$ for
       $.55 \leq X \leq .95$

If X represents secondary competence
   then: no effect on mean hours worked

If X represents shift length
   then: $Y = .392X + 1.177$ for
       $2 \leq X \leq 6$

If X represents men per shift
   then: no effect on mean hours worked

If X represents pace
   then: $Y = 2.32X + .732$ for
       $.7 \leq X \leq 1.3$

When workload is held constant, an increase in competence in the primary specialty is associated with a decrease in the time required to do the job. Competence in a secondary specialty had no effect on time worked with this scenario.
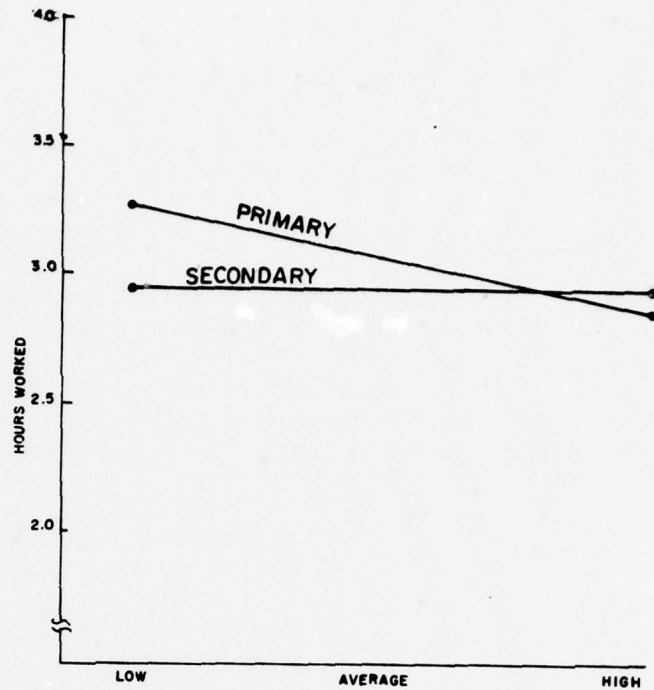
Figure I-A. Effect of competence in primary and secondary specialties on mean hours worked.

As shift length increases, the amount of time worked increases. The number of men per shift had no effect on the mean time worked in this scenario.
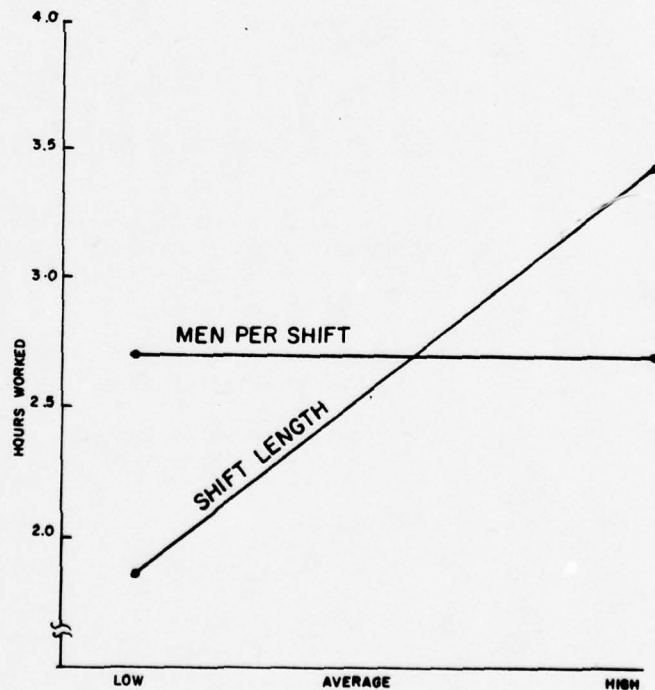
Figure I-B. Effect of shift length and men per shift or mean hours worked.

18

An increase in pace or working speed reduces the time to perform the job.
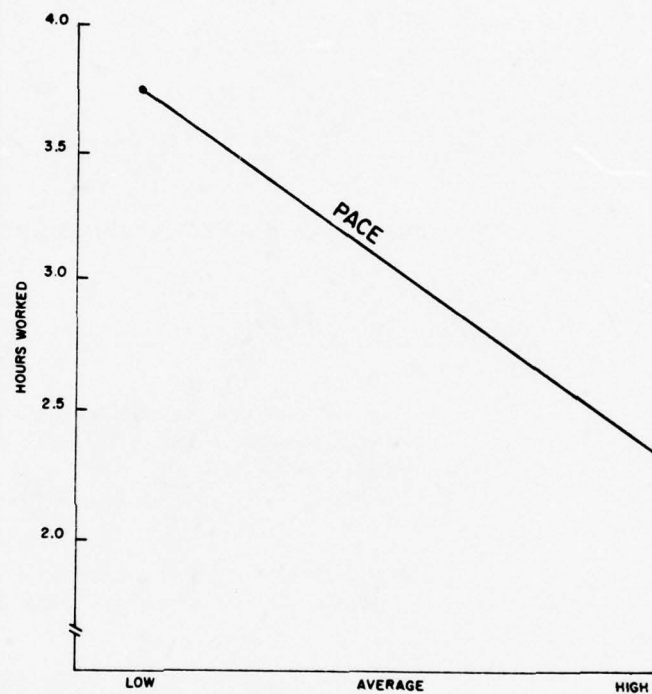
Figure I-C.   The effect of pace and mental load on mean hours worked.

19

II. Percentage of Success

This section presents the effects of selected independent variables on the percentage of tasks performed successfully on the first attempt. Eight independent variables were selected as most relevant for consideration. These variables are graphed in the following pairs:

A. Crew Size
   Shift Length

B. Primary Competence
   Secondary Competence

C. Mental Load
   Pace

D. Level of Aspiration
   Leader's Expectation

The equations for these relationships are presented in Table 7.

Table 7

Equations for Variables Affecting Percentage of Success

If Y represents the mean percentage of success on the first trial and X represents crew size
   then: $Y = 7.95X + 55.33$ for
   $3 \leq X \leq 5$

If X represents shift length
   then: $Y = 54.88 + 18.97 \ln X$ for
   $2 \leq X \leq 6$

If X represents primary competence
   then: $Y = 41.5X + 56.62$ for
   $.55 \leq X \leq .95$

If X represents secondary competence
   then: no effect on percent success

If X represents mental load
   then: $Y = -1.2X + 95.58$ for
   $1 \leq X \leq 9$

If X represents pace
   then: $Y = -22X + 109.06$ for
   $.7 \text{ (high)} \leq X \leq 1.3 \text{ (low)}$

If X represents level of aspiration
   then: $Y = 136X + 208.9$ for
   $.8 \leq X \leq 1.0$

If X represents leader's expectation
   then: $Y = -315X + 368.43$ for
   $.85 \leq X \leq .95$

20

Increase in crew size tends to increase task successes. This effect can probably be attributed to a reduction in job stress. Shift length also has a large impact on percentage of task success. Increase in the time available to do the job can generally be expected to have a parallel effect.
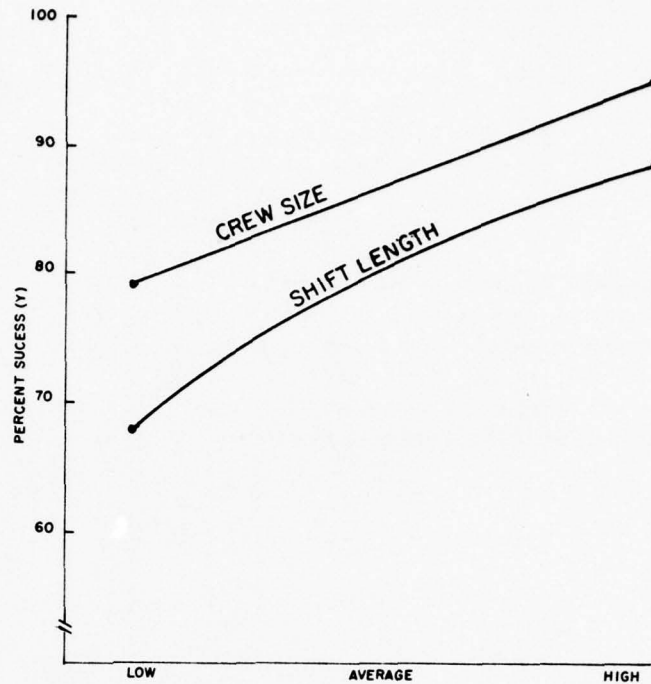

Figure II-A. Effect of crew size and shift length on the percentage of tasks performed successfully on the first trial.

Increase in competence in the primary specialty produces an increase in task successes. Secondary competency, on the other hand, has no effect on the success rate. This effect is probably due to the fact that, in the present simulation, relatively few tasks are performed in the secondary specialty. Accordingly, secondary specialty proficiency had little effect on the overall percentage of success across all tasks.

21
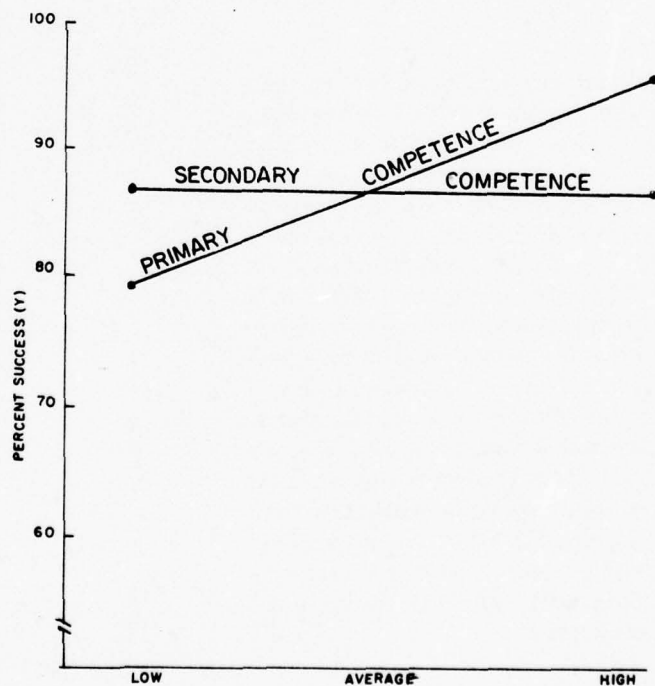
Figure II-B. Effect of competence in primary and secondary specialties on the percentage of tasks performed successfully on the first attempt.

An increase in the mental load im-
posed by the tasks causes a decrease
in the percentage of tasks performed
successfully on the first attempt.
This effect might be cancelled out
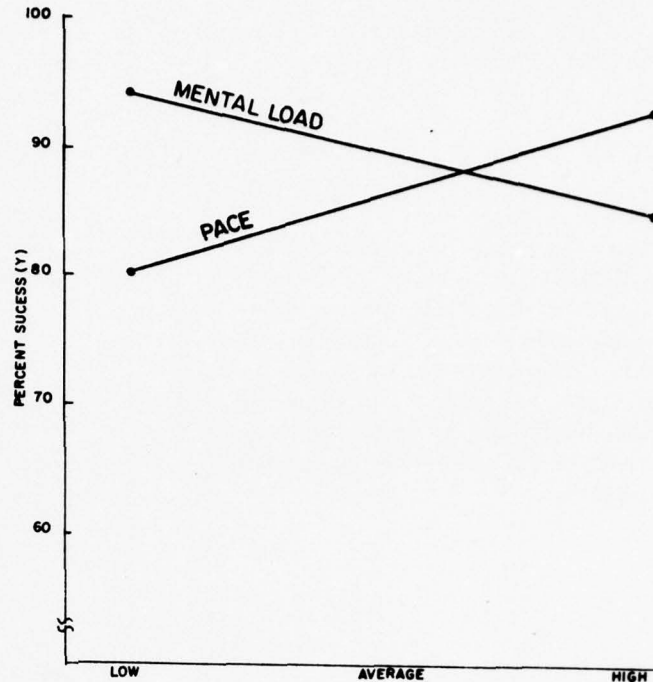by an increase in the pace of a crew-
man.

Figure II-C. Effect of mental load and pace on the
percentage of tasks performed success-
fully on the first attempt.

As his level of aspiration increases,
a person's standards of acceptable
performance also increase.   For
this reason, an increase in level of
aspiration produces a decrease in
the percentage of tasks completed
acceptably on the first attempt. An
increasing proportion of the tasks
must be touched up or repeated in or-
der for performance quality to meet
level of aspiration. Similarly, lead-
er's expectation increases the stand-
ards against which success on a job
is judged.   As leader's expectation
is increased, it can be expected that
more work will be rejected as im-
properly or incompletely perform-
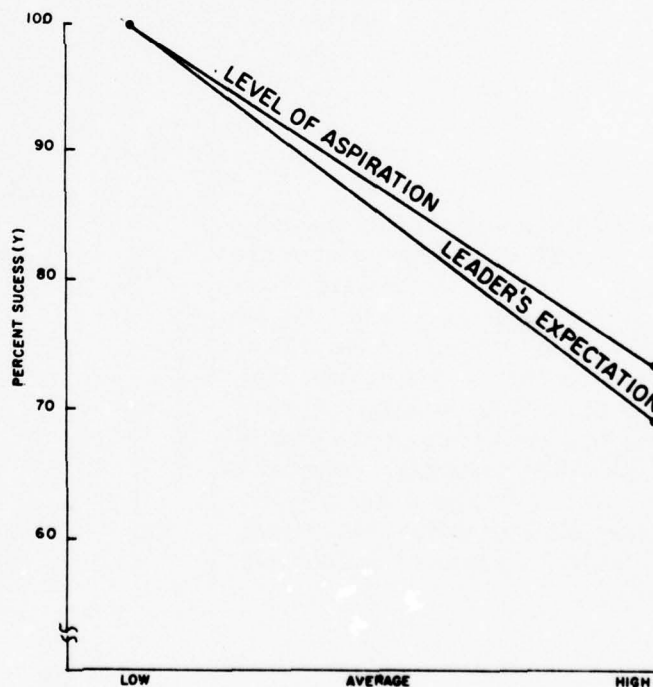ed.   This will result in more work
being rejected.

Figure II-D. Effect of level of aspiration and leader's
expectation on the percentage of tasks
performed successfully on the first.
attempt

22

III. Unmanned Station Hours

Unmanned station hours represent the number of man hours of work which were not performed because of personnel unavailability.

Six independent variables were found to produce consistent and meaningful effects on unmanned station hours. These variables are grouped in the following pairs:

      A. Pace
         Primary Competence

      B. Level of Aspiration
         Leader's Expectation

      C. Shift Length
         Men Per Shift

The equations describing the relationship between these independent variables and unmanned station hours are shown in Table 8.

Table 8

Equations for Variables Affecting Unmanned Station House

If Y represents the unmanned station hours
and X represents pace
    then: $Y = 19.44X - 14.964$ for
        $.7 \text{ (high)} \leq X \leq 1.3 \text{ (low)}$

If X represents competence in primary specialty
    then: $Y = -1.14X + 3.877$ for
        $.55 \leq X \leq .95$

If X represents level of aspiration
    then: $Y = 39.5X - 29.323$ for
        $.80 \leq X \leq 1.00$

If X represents leader's expectation
    then: $Y = 39.3X - 32.98$ for
        $.85 \leq X \leq .95$

If X represents shift length
    then: $Y = 59.327 - 35.573 LNX$ for
        $2 \leq X \leq 6$

If X represents men per shift
    then: $Y = 713.57E - 1.397X$ for
        $3 \leq X \leq 5$

Both pace and primary competence reduce the unmanned station hours, i. e. , work left undone. However, the effect of an increase in working speed, pace, is much greater than the effect of an increase in proficiency in the primary specialty. However, unmanned station hours say nothing about the quality of the work done. The measure only reflects the work left undone.
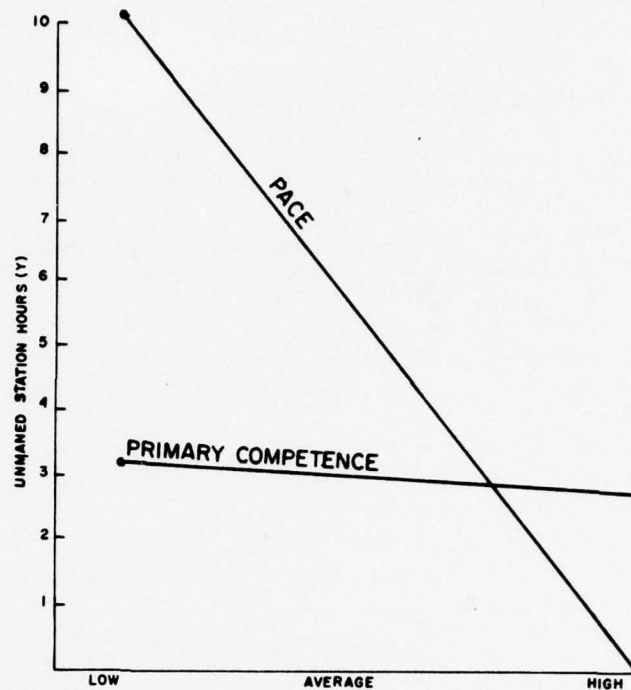

Figure III-A. Effect of pace and level of competence in primary specialty on unmanned station hours.

An increase in the standards of work, whether caused by an increase in the level of aspiration or an increase in leader's expectation produces, an increase in the number of unmanned station hours.
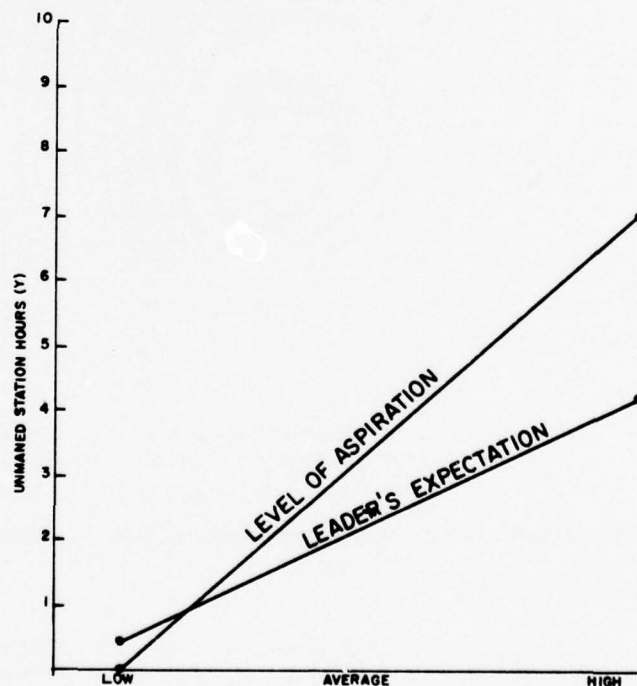
Figure III-B. Effect of level of aspiration and leader's expectation on unmanned station hours.

24

An increase either in the shift length or men per shift decreases the number of unmanned station hours.
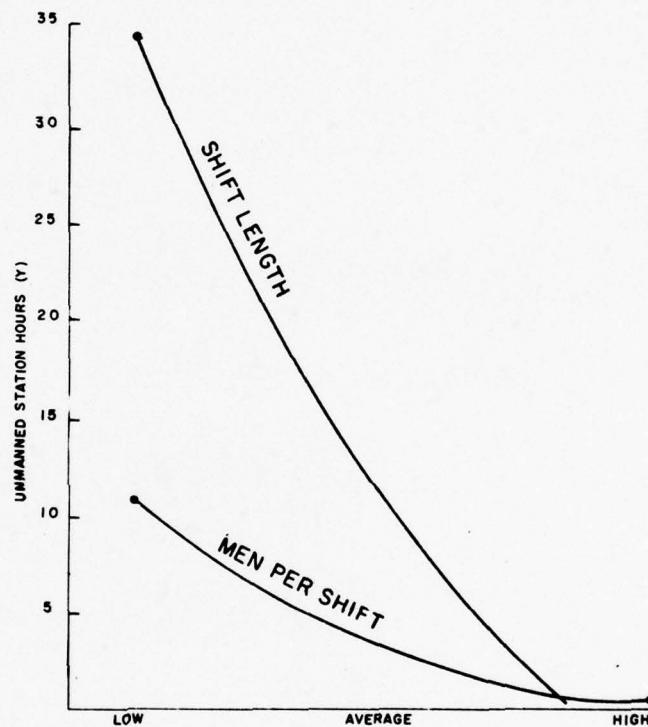
Figure III-C. Effect of shift length and men per shift on unmanned station hours.

25

IV. Percentage of Tasks Ignored

Events or tasks may be ignored by crew members because there is insufficient time to do the tasks because required personnel are unavailable or because the crew members are under stress. System design which imposes a need to ignore scheduled tasks is considered to represent a highly undesirable situation.

Eight independent variables are graphed to show their effect on tasks ignored. These variables are presented in the following groups:

> A. Crew Size
>   Pace
>
> B. Primary Competence
>   Secondary Competence
>
> C. Shift Length
>
> D. Leader's Expectation
>   Level of Aspiration
>   Mental Load

The equations which reflect these curves are given in Table 9.

Table 9

Equations for Variables Affecting Percentage of Events Ignored

If Y represents the percentage of events
ignored and X represents crew size
   then: $Y = -8.095X + 38.37$ for
           $3 \leq X \leq 5$

If X represents pace
   then: $Y = 15.14X - 12.252$ for
           $.70 \text{ (high)} \leq X \leq 1.30 \text{ (low)}$

If X represents primary competence
   then: $Y = -3.06X + 3.151$ for
           $.55 \leq X \leq .95$

If X represents secondary competence
   then: no effect

If X represents shift length
   then: $Y = -6.195X + 33.273$ for
           $2 \leq X \leq 6$

If X represents leader's expectation
   then: $Y = 27.8X - 23.74$ for
           $.85 \leq X \leq .95$

If X represents level of aspiration
   then: $Y = 11.1X - 9.017$ for
           $.80 \leq X \leq 1.00$

If X represents mental load
   then: $Y = .106X + .196$ for
           $1 \leq X \leq 9$

26

The percentage of tasks ignored de-
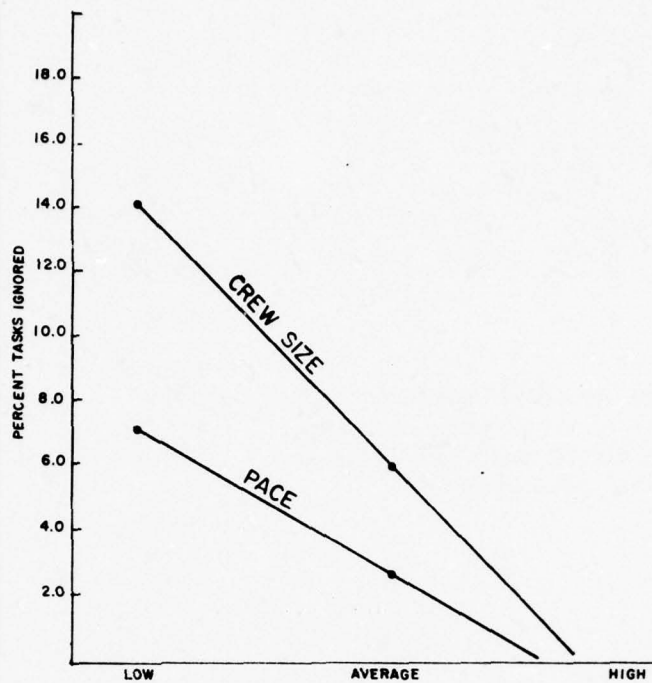creases as crew size increases and
as crew pace increases.

Figure IV-A. Effect of crew size and pace on percent-
age of tasks ignored.

An increase in competence in the
primary specialty results in a de-
crease in the percentage of tasks
ignored.   Variation in competency
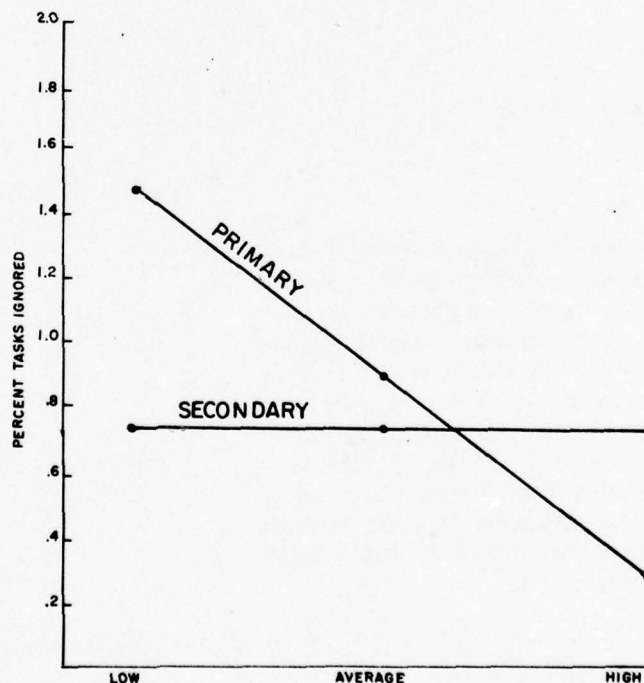in the secondary specialty has no ef-
fects on tasks ignored.

Figure IV-B. Effect of competence in primary and
secondary specialties on percentage of
tasks ignored.

27

Changing the shift length while keeping the amount of work to be done constant significantly affects the percentage of tasks ignored.
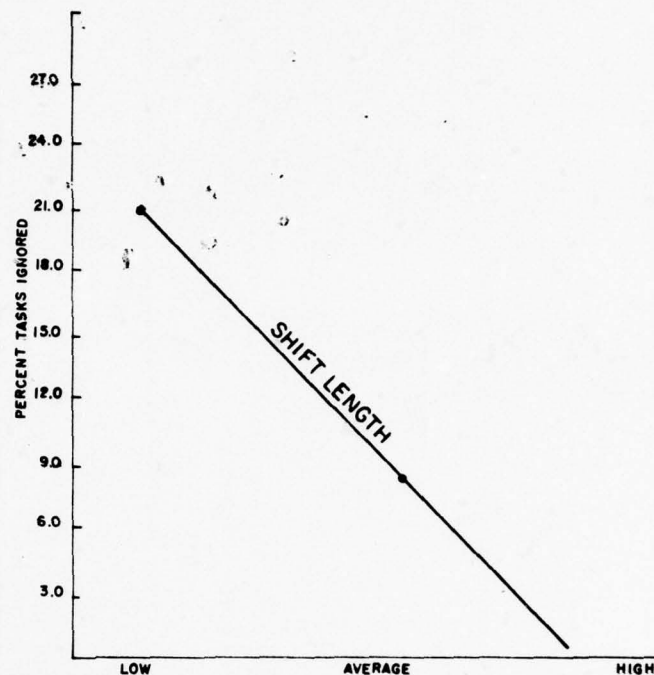
Figure IV-C. Effect of shift length on the percentage of tasks ignored.

An increase in the standards of task success (level of aspiration or leader's expectation) produces an increase in the percentage of events ignored. This effect is similar in magnitude to the effect on increasing the mental load of the events to be performed. These effects, although consistent, are small in magnitude as compared with the effects of pace, crew size, and shift length on tasks ignored.
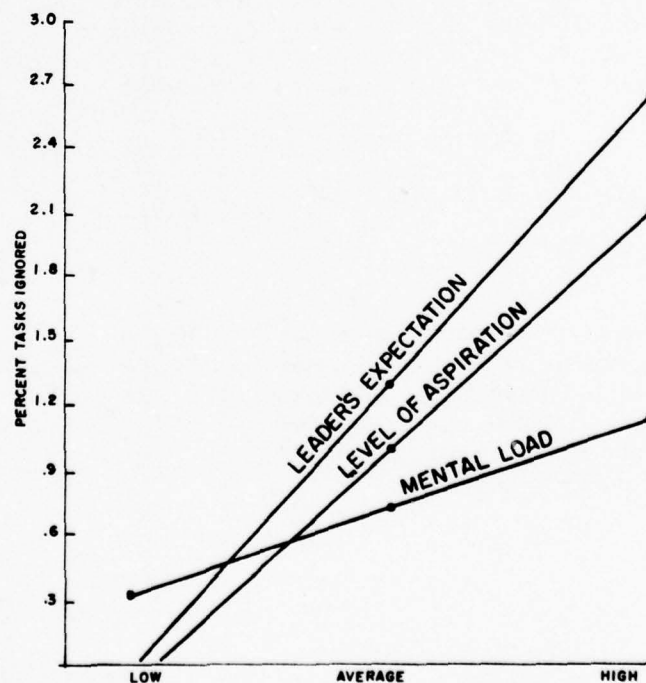
Figure IV-D. Effect of leader's expectation, level of aspiration, and mental load on percentage of tasks ignored.

28

V. & VI. <u>System Reliability and System Availability</u>

Due to their interdependence, system reliability and system availability are plotted on the same axes for several independent variables. These independent variables are:

A. Leader's Expectation

B. Level of Aspiration

C. Mental Load

In addition, the effect of primary competence on system reliability and the effect of men per shift and shift length on system availability are presented.

The equations for these plots are given in Tables 10 and 11.

Table 10

<u>Equations for Variables Affecting System Reliability</u>

If Y represents system reliability and
X represents leader's expectation
then: $Y = -2.9X + 3.467$ for
$.85 \leq X \leq .95$

If X represents level of aspiration
then: $Y = -1.2X + 1.953$ for
$.80 \leq X \leq 1.00$

If X represents mental load
then: $Y = -.0105X + .9605$ for
$1 \leq X \leq 9$

If X represents primary competence
then: $Y = .38X + .599$ for
$.55 \leq X \leq .95$

Table 11

<u>Equations for Variables Affecting System Availability</u>

If Y represents system availability and
X represents leader's expectation
then: $Y = -.8X + 1.65$ for
$.85 \leq X \leq .95$

If X represents level of aspiration
then: $Y = -.5X + 1.367$ for
$.80 \leq X \leq 1.00$

If X represents mental load
then: $Y = -.007X + .983$ for
$1 \leq X \leq 9$

If X represents men per shift
then: $Y = .09X + .53$ for
$3 \leq X \leq 5$

If X represents shift length
then: $Y = .305X - .663$ for
$2 \leq X \leq 6$

An increase in leader's expectation produces decrease in system availability and much larger decrement in system reliability. This decrement is directly attributable to the higher human failure rate associated with excessively high standards of performance.
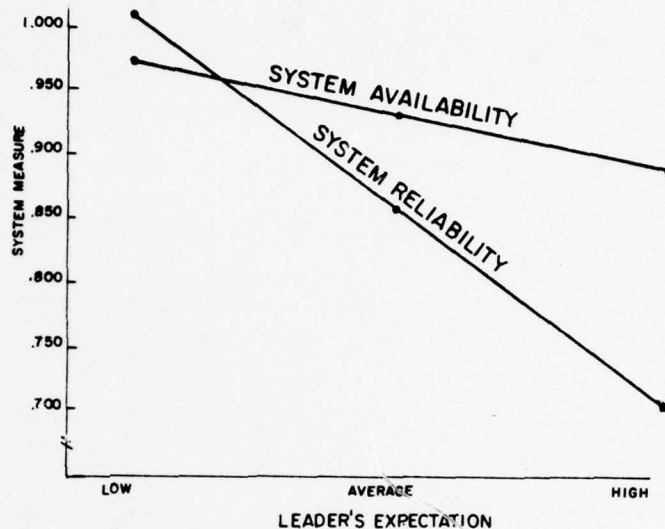

Figure V & VI-A. Effect of leader's expectation on system reliability and system availability.

High levels of aspiration produce lower levels of system availability and system reliability. Setting reasonable personnel performance standards has a strong effect on system reliability and availability.
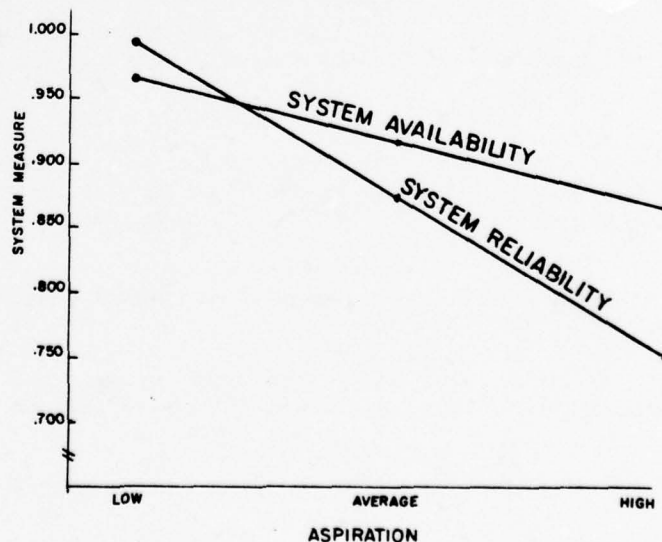
Figure V & VI-B. Effect of level of aspiration on system reliability and system availability.

30

An increase in mental load required
in performance of tasks produces a
decrement in system availability and
system reliability.
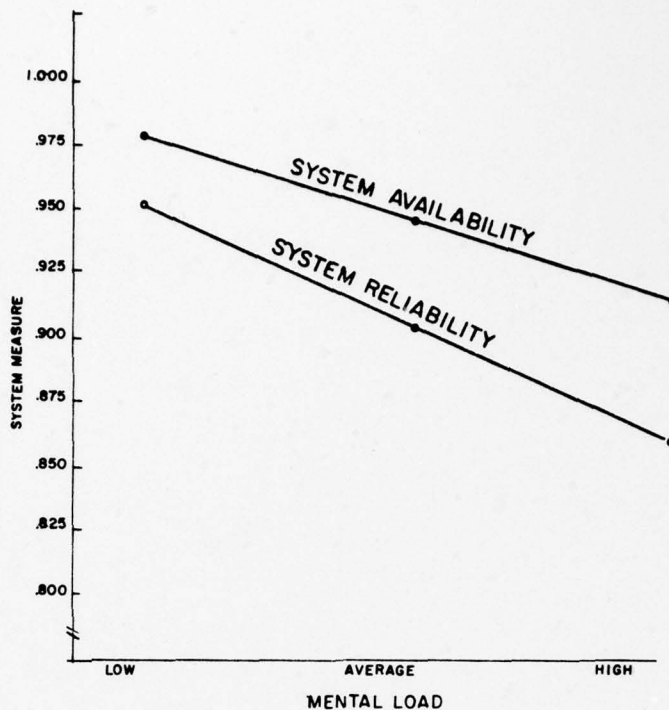
Figure V & VI-C. Effect of mental load on system
reliability and system availability.

An increase in crew training, as re-
flected in increased competence in
the primary competence, can be ex-
pected to produce a large increase
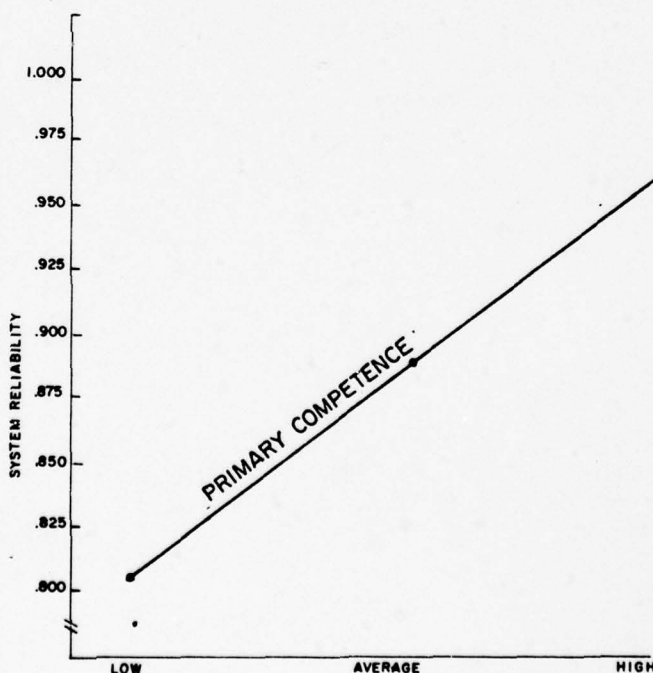in system reliability.

Figure V-D. Effect of competence in primary
specialty on system reliability.

31

System availability can be increased by increasing number of men assigned per shift and, to a greater extent, by increasing shift length.
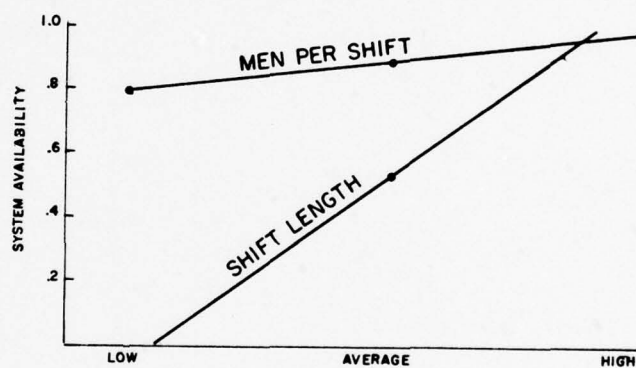
Figure VI-D. Effect of men per shift and shift length on system availability.

VII. **System MTTR**

 System mean time to repair includes both equipment repairs and reperform-
ance of operational tasks because of personnel failure to perform adequately.

 The effects of five variables are shown on system MTTR. These variables
are grouped as follows:

   A. Pace
     Shift Length

   B. Mental Load
     Aspiration
     Leader's Expectation

 The equations describing the relationship between these variables and sys-
tem MTTR are presented in Table 12.

Table 12

Equations for Variables Affecting System MTTR

 If Y represents system MTTR and X
 represents pace
   then: $Y = .267X - .027$ for
       $.70$ (high) $\leq X \leq 1.30$ (slow)

 If X represents shift length
   then: $Y = .018X + .18$ for
       $2 \leq X \leq 6$

 If X represents mental load
   then: $Y = .007X + .174$ for
       $1 \leq X \leq 9$

 If X represents level of aspiration
   then: $Y = -1.45 + 1.615$ for
       $.8 \leq X \leq 1.0$

 If X represents leader's expectation
   then: $Y = -2.4X + 2.46$ for
       $.85 \leq X \leq .95$

33

An increase in crewman pace pro-
duces a decrease in mean time to
repair.   Shift length increases, on
the other hand, produce increased
MTTR. This result can be explain-
ed by the fact that when more time
is available to perform all tasks, in-
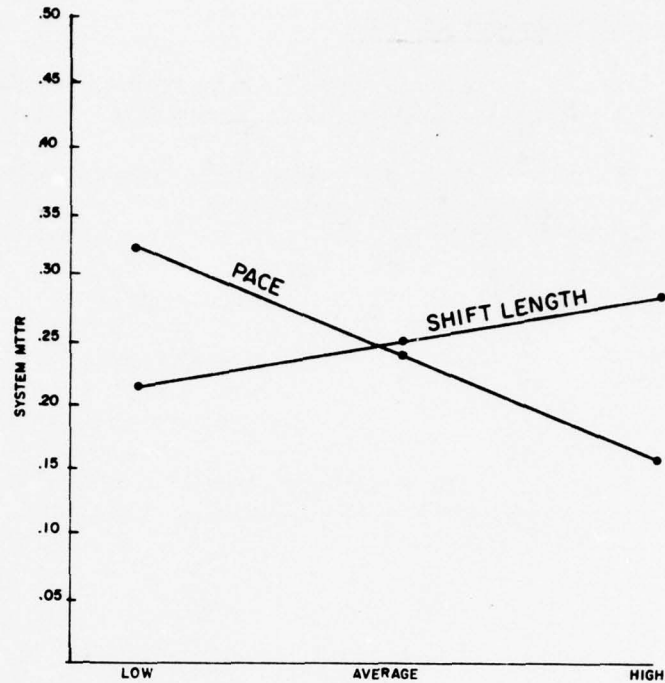cluding repairs, the amount of time
spent on the tasks is increased.

Figure VII-A.   Effect of pace and shift length on
system MTTR.

Task mental load increases produce
an increased MTTR. This increase
is due to both increased human fail-
ures and increased time required to
correct the failures.   Increases in
level of aspiration and leader's ex-
pectation produce a reduced system
MTTR.
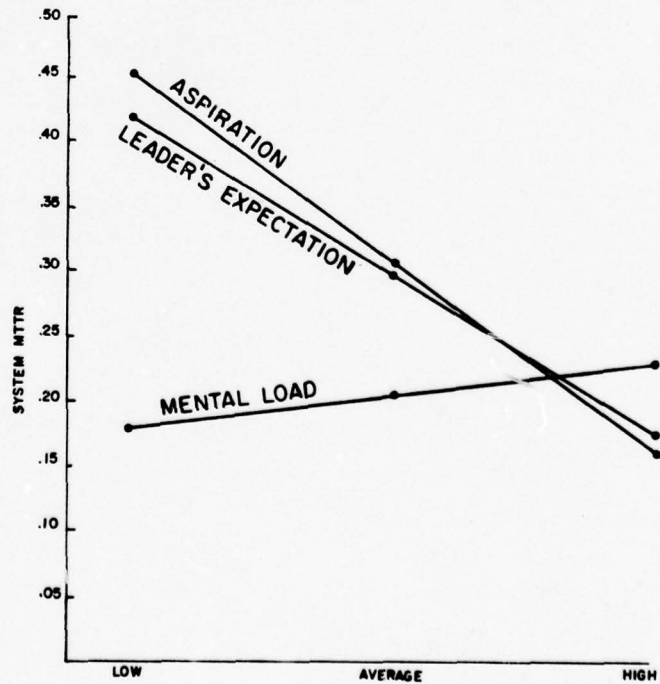
Figure VII-B.   Effect of mental load, level of
aspiration, and leader's expectations
on system MTTR.

34

VIII. Human Reliability

Human reliability is affected by a number of variables. Six independent variables are shown in their relationship to human reliability. These variables are presented in two groups:

A. Primary Competence
   Pace
   Shift Length

B. Level of Aspiration
   Mental Load
   Leader's Expectation

Table 13 shows the equations relating these independent variables to human reliability.

Table 13

Equations for Variables Affecting Human Reliability

If Y represents human reliability and X represents primary competence
then: $Y = .41X + .576$ for
$.55 \leq X \leq .95$

If X represents pace
then: $Y = -.087X + .981$ for
$.70 \leq X \leq 1.30$

If X represents shift length in hours
then: $Y = -.008X + .9$ for
$2 \leq X \leq 6$

If X represents level of aspiration
then: $Y = -1.3X + 2.043$ for
$.80 \leq X \leq 1.00$

If X represents mental load
then: $Y = -.009X + .949$ for
$1 \leq X \leq 9$

If X represents leader's expectation
then: $Y = -3X + 3.56$ for
$.85 \leq X \leq .95$

Increased crewman training, as reflected by both proficiency in primary specialty and pace, result in increased human reliability. Primary competence, in particular, has a major impact on human reliability. This effect is probably due to the elimination of time pressure motivation with an excessively long shift length.
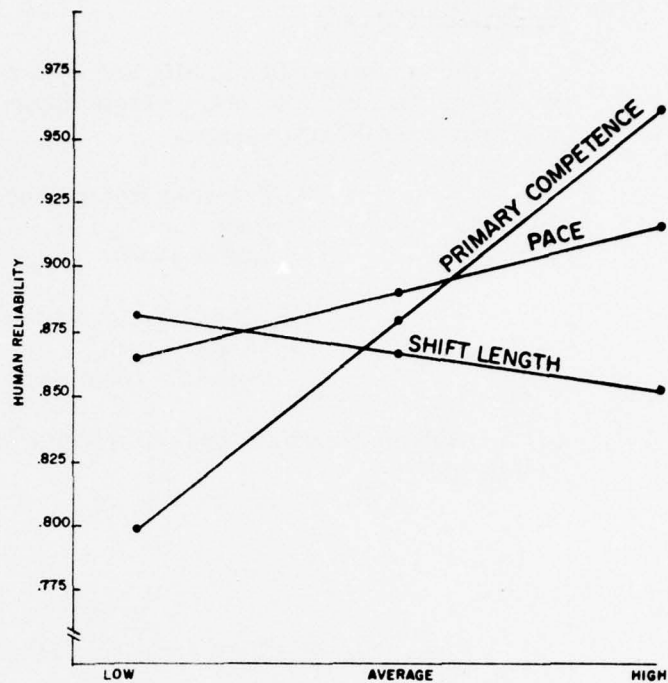

Figure VIII-A. Effect of pace, competence in primary specialty, and shift length on human reliability.

A decrease in human reliability accompanies increases in level of aspiration, leader's expectation, and mental load. All of these factors increase the number of task failures. Accordingly, a decrease in human reliability would be expected.
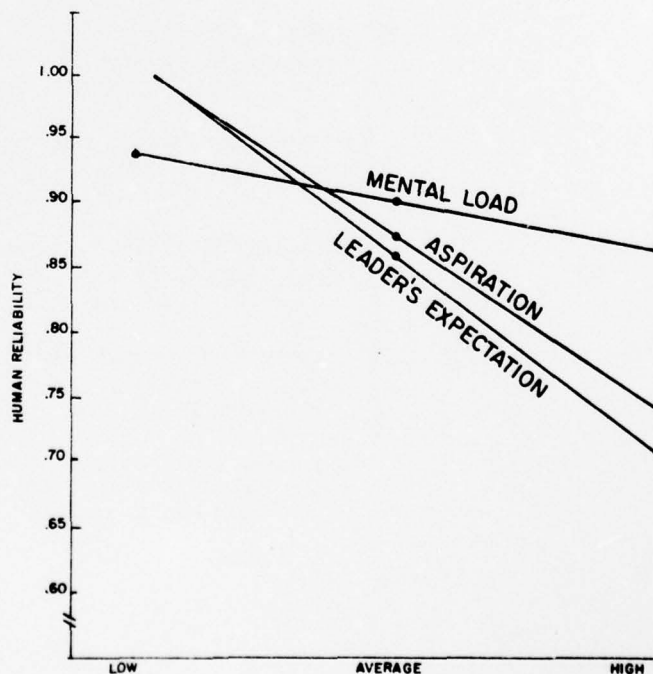
Figure VIII-B. Effect of level of aspiration, mental load, and leader's expectation on human reliability.

36

IX. Human Availability

       The effects of six independent variables were plotted to show their relative impact on human availability.   These variables are grouped in two sets:

            A. Pace
                Men Per Shift
                Shift Length

            B. Level of Aspiration
                Mental Load
                Leader's Expectation

       The equations relating these independent variables to the dependent variable, human availability, are displayed in Table 14.

Table 14

Equations for Variables Affecting Human Availability

If Y represents human availability and X
represents pace
    then: $Y = -.327X + 1.251$ for
          $.70 \text{ (fast)} \leq X \leq 1.30 \text{ (slow)}$

If X represents men per shift
    then: $Y = .08X + .603$ for
          $3 \leq X \leq 5$

If X represents shift length
    then: $Y = .31X - .67$ for
          $2 \leq X \leq 6$

If X represents level of aspiration
    then: $Y = -.6X + 1.483$ for
          $.80 \leq X \leq 1.00$

If X represents mental load
    then: $Y = -.004 + .986$ for
          $1 \leq X \leq 9$

If X represents leader's expectation
    then: $Y = -.7X + 1.59$ for
          $.85 \leq X \leq .95$

Human availability is increased by increasing the crew's working speed (pace), by increasing number of men assigned to the shift and by increasing shift length. Increasing shift length effectively increases the time available for task performance and thereby the availability of the crew.
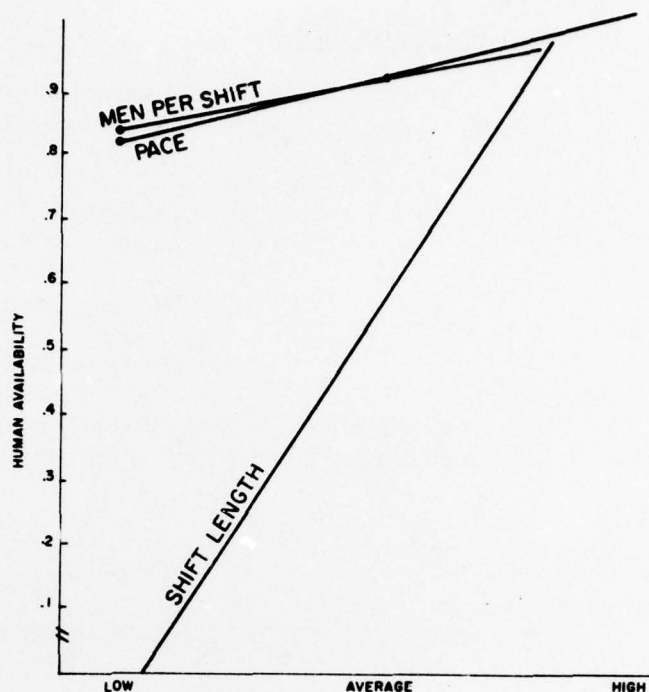

Figure IX-A. Effect of pace, men per shift, and shift length on human availability.

Human availability is decreased by factors which increase the task difficulty such as mental load and by factors which increase the standards, such as level of aspiration and leader's expectation, with which task performance is judged.
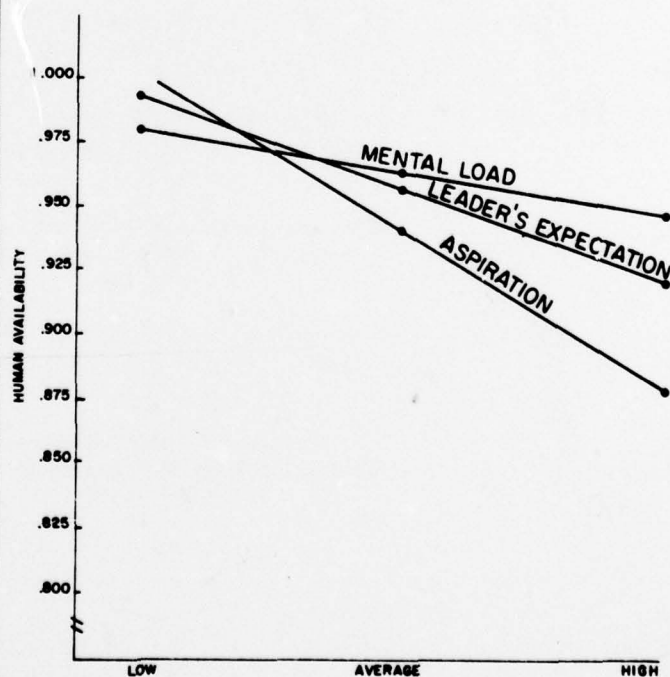
Figure IX-B. Effect of level of aspiration, mental load, and leader's expectations on human availability.

38

X. Human MTTR

Human mean time to repair is defined as the mean time required to touch up or repeat tasks performed inadequately on the first attempt.

Four variables were selected for graphic presentation of their effect on human MTTR. The variables are presented in two groups:

A. Pace
   Mental Load

B. Level of Aspiration
   Leader's Expectation

The equations relating these variables to human MTTR are shown in Table 15.

Table 15

Equations for Variables Affecting Human MTTR

If Y represents human MTTR and X represents pace
   then: $Y = .293X - .093$ for
          .70 (fast) $\leq X \leq$ 1.30 (slow)

If X represents mental load
   then: $Y = .003X + .177$ for
          $1 \leq X \leq 9$

If X represents level of aspiration
   then: $Y = X - .767$ for
          $.80 \leq X \leq 1.00$

If X represents leader's expectation
   then: $Y = 2X - 1.677$ for
          $.85 \leq X \leq .95$

39

An increase in crewman speed (pace) produces a decrease in human mean time to repair. Mental load, due to increasing task difficulty, results in an increased human MTTR.
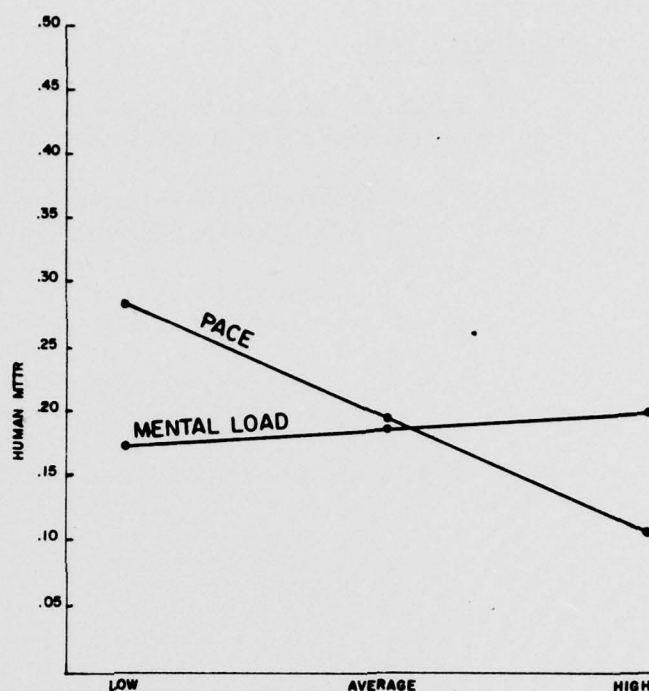
Figure X-A.   Effect of pace and mental load on human MTTR.

Increases in level of aspiration and leader's expectation produce very similar increases in human mean time to repair (the curves are super-imposed).
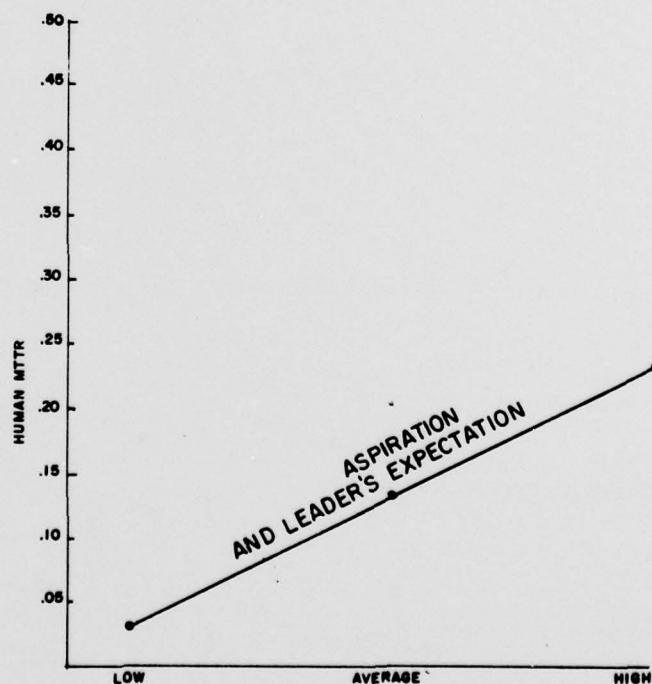

Figure X-B.   Effect of level of aspiration and leader's expectations on human MTTR.

40

XI. Maximum Stress

That system design which minimizes the stress level placed on the system operators is preferred over that which stresses the operator.

Two independent variables are presented relative to their effects on operator stress:

A. Men Per Shift
   Pace

Table 16 presents the equations relating the independent variables to maximum stress level.

Table 16

Equations for Variables Affecting Maximum Stress

```
If Y represents maximum stress and X
represents man per shift
   then:  Y = -.8X + 5.272 for
          3 ≤ X ≤ 5

If X represents pace
   then:  Y = 3.307X - 1.255 for
          .70 (high) ≤ X ≤ 1.30 (low)
```

Maximum stress is increased by too high a work load. Stress may be reduced either by increasing the work speed capability (pace) of the crew or by increasing the men available per shift.
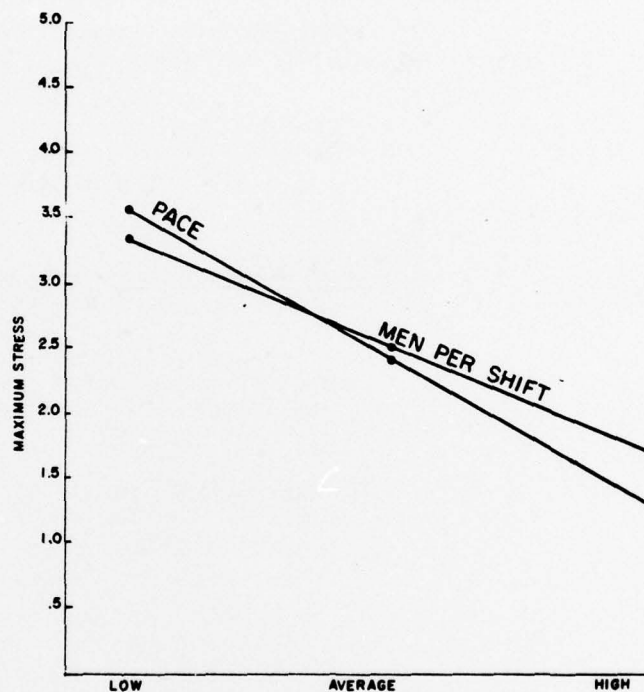
Figure XI-A. Effect of pace and men per shift on maximum stress level.

42

XII. Hazard

An effective system design aslo minimizes the hazard level to which the crewmen are exposed. Four human oriented variables are shown which affect hazard level. These variables are:

A. Pace
   Primary Competence

B. Shift Length
   Men Per Shift

These variables and the equations relating them to hazard level are shown in Table 17.

Table 17

Equations for Variables Affecting Hazard Level

If Y represents hazard level and X
represents pace
    then: Y = 58.5X + 14.797 for
          .7 (fast) ≤ X ≤ 1.30 (slow)

If X represents primary competence
    then: Y = -20.26X + 87.545 for
          .55 ≤ X ≤ .95

If X represents shift length
    then: Y = 9.34X + 28.083 for
          2 ≤ X ≤ 6

If X represents men per shift
    then: Y = 8.695X + 34.32 for
          3 ≤ X ≤ 5

43

Increased personnel training result-
ing in increased work speed capa-
bility or increased overall profici-
ency in primary specialty reduces
the overall hazard risk of the crew-
man.
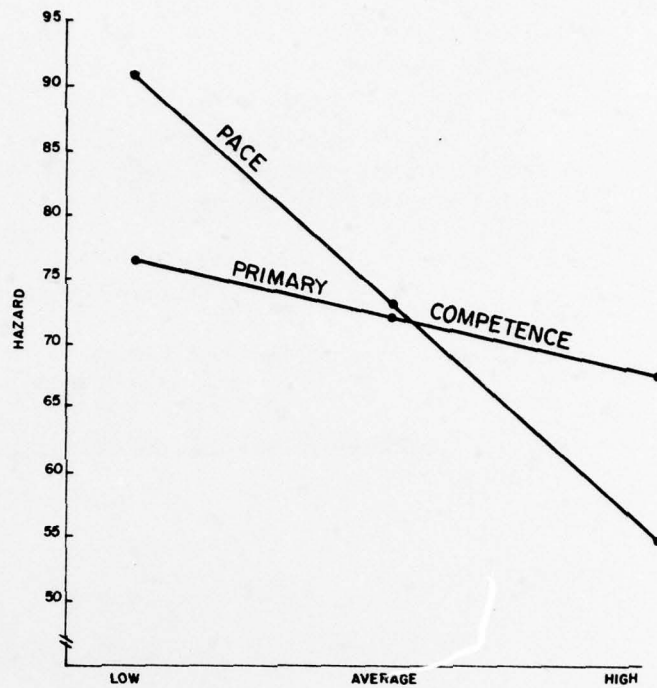
Figure XII-A. Effect of pace and competence in
primary specialty on mean hazard level.

Factors which increase the number
of manhours during which crewmen
are exposed to hazards increase the
mean hazard level. Increases in the
number of men assigned to a shift
and increasing shift length lead to
an increase in overall hazard level.
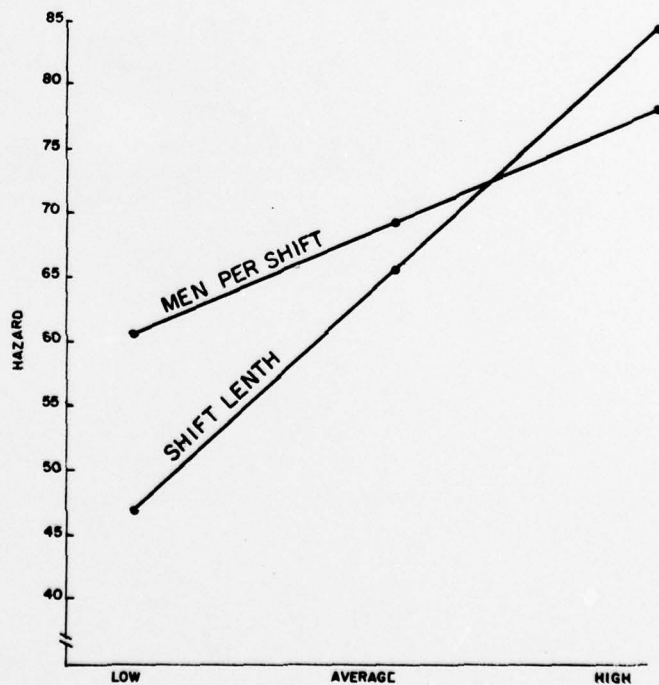
Figure XII-B. Effect of shift length and men per
shift on mean hazard level.

44

XIII. Human Availability and Manpower Utilization Interaction

Human availability reflects the degree to which personnel are available to perform tasks at the time that the tasks should be done. Manpower utilization, on the other hand, is a measure of the degree to which crewmen are kept busy during their work shift.

The tradeoff relationship between these two measures of system performance are shown over a range of two variables:

A. Pace

B. Shift Length

Table 18 presents the equations relating the two dependent variables, human availability and manpower utilization, across the range of the independent variables.

Table 18

Equations for Variables Relating Human Availability to Manpower Utilization

If Y represents manpower utilization and X represents human availability
$$Y = -6.654X + 9.2$$
$$.70 \leq X \leq 1.30$$

As shift length increases
$$Y = 1.105X + 2.117$$
$$2.0 \leq X \leq 5.0$$

Increasing crewman pace produces a decrease in manpower utilization and an increase in human availability. This means that if maximum human availability is required, a sacrifice in the effectiveness of manpower utilization must be accepted.
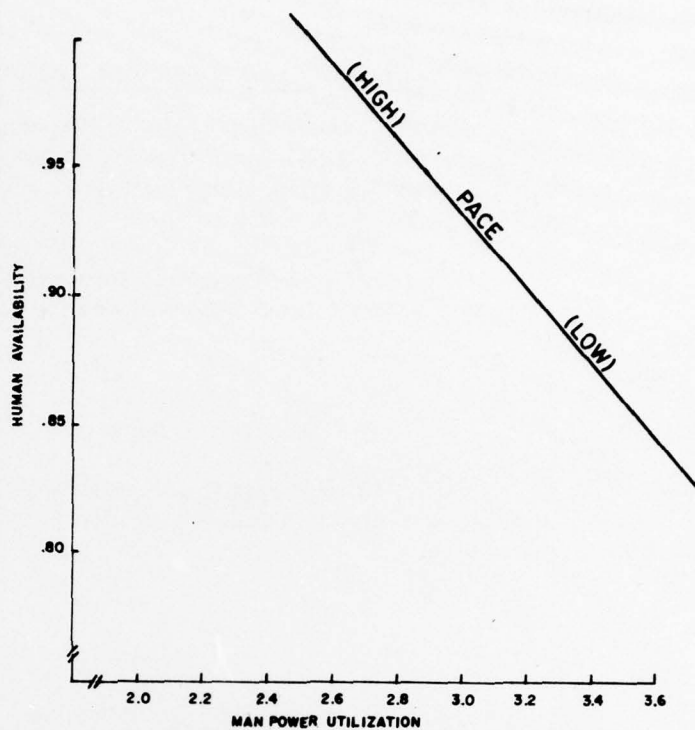

Figure XIII-A. Effect of pace on the relationship between human availability and manpower utilization.

Increasing the shift length, which effectively decreases the work load, produces an increase in human availability but produces a decrease in manpower utilization. If maximum manpower utilization is required, there will be a decrease in availability.
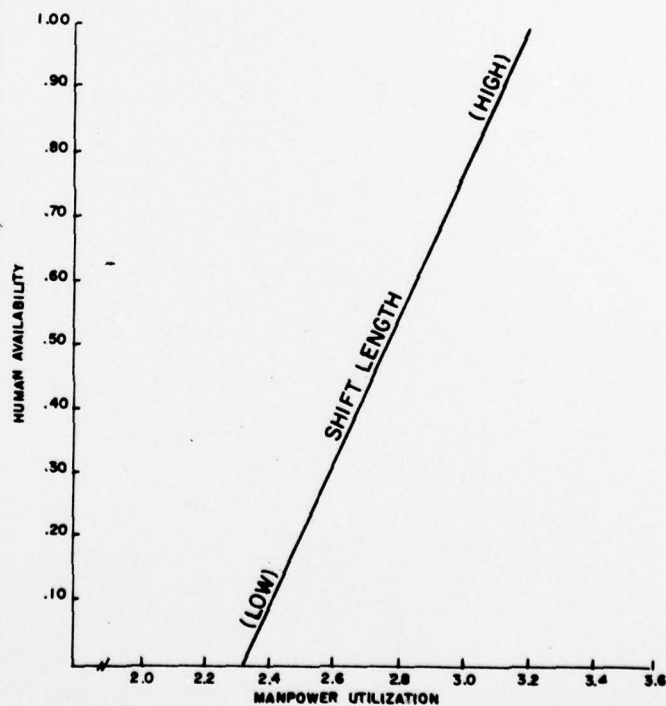
Figure XIII-B. Effect of shift length on the relationship between human reliability and manpower utilization.

46

CHAPTER III

SUMMARY AND DISCUSSION

A total of 68 curves on 33 graphs was produced to show the relationships between human oriented variables and measures of system performance. These curves will allow a system planner or designer to assess the relative impact of various human oriented design considerations

The tradeoff curves were derived through computer simulation of the operator tasks in a representative mission over a number of parametric variations of crew composition and work conditions. The representative mission was designed to be analogous to a number of different types of Navy mission. Accordingly, the relationships determined for this mission may be expected to be reasonably generalized. For any specific system, a more accurate description of the tradeoff relationships could be obtained through a simulation of the system itself.

Certainly, independent variables other than those here considered will affect system performance. The independent variables included in the present set of tradeoff curves were those embedded within the simulation model employed. In selecting these variables for inclusion in the simulation model, the model developers attempted to include those human oriented variables which they believed to be most salient to system performance.

Human performance reliability continues to represent a salient aspect of system performance. We are aware of no prior attempt to develop systematically and present tradeoffs such as those which were presented in Chapter II of this report.

In developing the various tradeoff curves, the attempt was to present the information in a form which would be useful to engineers who are responsible for system design and development. It is believed that the presentation method employed is compatible with the handbook type of presentation with which design and development engineers are accustomed. The various tradeoff curves will not make a design decision for the engineer Indeed, that was not their purpose. However, they should provide one additional data basis for various design decisions. The final design decision continues to rest with the engineer.

REFERENCES

Leahy, W. R., Siegel, A. I. & Lamb, J. *Human reliability in a combined sonar system; II. Human reliability for the AN/SQS-26, LAMPS, and AN/SQR-19 system.* Wayne, Pa.: Applied Psychological Services, 1976.

Siegel, A. I., Wolf, J. J., & Lautman, M. R. *A model for predicting integrated man-machine system reliability; II. Model logic and description.* Wayne, Pa.: Applied Psychological Services, 1974.

Siegel, A. I., Leahy, W. R., & Wiesen, J. P. *Applications of human performance reliability evaluation concepts and demonstration guidelines.* Wayne, Pa.: Applied Psychological Services, 1977.

Siegel, A. I., Wolf, J. J., & Cosentino, J. *Digital simulation of the performance of intermediate size crews: Application and validation of a model for crew simulation.* Wayne, Pa.: Applied Psychological Services, 1972.

DISTRIBUTION LIST

1   Hydrospace Research Corporation
    5541 Nicholson Lane
    Rockville, MD   20852
    Attn: Frank P. Falci, Jr.

1   IBM-FSD
    Owego, NY 13827
    Attn: Robert M. Evanson

1   Interstate Electronics Corporation
    707 East Vermont Avenue
    Anaheim, CA 92803
    Attn: Jack Watson

1   Philco-Ford Corporation
    3900 Welsh Road
    Willow Grove, PA 19090
    Attn: Robert Smarglassi

1   Presearch, Inc.
    8720 Georgia Avenue
    Silver Spring, MD
    Attn: Ronald D. Byrd

1   Technical Director
    Personnel Research &
      Development Laboratory
    Washington Navy Yard
    Washington, DC   20390
    Attn: Code 93

1   Commanding Officer
    Naval Personnel & Training
      Research Laboratory
    San Diego, CA   92152

1   General Electric Corporation
    HMED
    Farrell Road Plant
    Syracuse, NY
    Attn: Philip E. Pedley

1   Honeywell, Inc.
    1200 E. San Bernadion Road
    West Covina, CA 91790
    Attn: Morris H. Stephenson

1   Commander
    Submarine Development Group II
    US Naval Submarine Base (NLON)
    Groton, CT 06340

1   Commander
    Anti-Submarine Warfare Force
    US Atlantic Fleet
    Norfolk, VA 23511

1   Human Factprs Department, Code 55
    Attn: Dr. J.J. Regan
    Naval Training Device Center
    Orlando, FL   32813

1   Institute for Defense Analyses
    400 Army Navy Drive
    Arlington, VA   22202
    Attn: Dr. R.W. Sinaiko

1   Project Manager
    Anti-Submarine Warfare Systems Project
      (PM-4)
    Department of the Navy
    Washington, DC   20362
    Attn: ASW 13
           ASW 55

1   Anacapa Sciences, Inc.
    226 E. DeLa Guerra
    Santa Barbara, CA 92101

1   Bolt, Baranek & Newman, Inc.
    21120 Vanowen Street
    Canoga Park, CA 01303
    Attn: Ronald L. Spooner

1   EG&E Washington Analytical
      Services Center
    Rockville, MD
    Attn: John L. Bowerman

1   Lelco Electronics
    General Motors Corporation
    Santa Barbara Research Park
    Goleta, CA 92017
    Attn: Robert F. Podlesny

1   Diagnostic/Retrieval Systems, Inc.
    237 West Lincoln Avenue
    Mount Vernon, NY 10550
    Attn: David E. Gross

1   Charles S. Drater Laboratories
    MIT
    Cambridge, Mass.
    Attn: Steven E. Heeger

1   Edo Corporation
    College Point, NY 11356
    Attn: John P. Callahan

1   General Dynamics Corporation
    Electric Boat Division
    Groton, CT
    Attn: Adrianus J. VanWoerkom

1   Commander
    Anti-Submarine Warfare Force
    US Pacific Fleet
    FPO San Francisco, CA

1   Commanding Officer
    Naval Intelligence Support Center
    4301 Suitland Road
    Washington, DC 20390

1   Project Manager
    SSN 688 Class Submarine Project
      (PM-13)
    Department of the Navy
    Washington, DC   20362

1   Commanding Officer
    Atlantic Fleet ASW Tactical School
    Norfolk, VA 24511

1   US Navy Post Graduate School
    Monterey, CA 93940
    Attn: Library

1   Director
    Strategic Systems Project Office (PM-1)
    Department of the Navy
    Washington, DC 20362

1   Bendix Corporation
    11600 Sherman Way
    N. Hollywood, CA 48075

1   Bendix Corporation
    Bendix Center
    Southfield, MI 48075
    Attn: Rolf K. Muelier

1   Chesapeake Instruments, Inc.
    Shadyside, MD 20852
    Attn: Stanley G. Lemon

1   Chesapeake Instruments, Inc.
    Shadyside, MD
    Attn: Mr. Robert Santin

1   Commander, ASW Forces
    Atlantic Fleet

1   Scientific Advisory Team
    Norfolk, VA 23511
    Attn: 71

1   Commanding Officer
    Naval Personnel Training
      Research Laboratory
    San Diego, CA 92152

1   Human Factors Engineering
      Branch
    Attn: Dr. George Moeller
    Submarine Medical Research
      Laboratory
    Naval Submarine Base
    Groton, CT

1   USN Post Graduate School
    Monterey, CA
    Attn: Prof. J. Arima

1   Commander
    Naval Electronics System
      Command
    Washington, DC 20362
    Attn: 03

1   Dr. A.L. Slafkesky
    Scientific Advisor
    Commandant of the Marine
      Corps Code AX
    Washington, DC 20380

1   Commander
    Human Factors Engineering
      Branch
    Code 5342
    Point Mugu, CA 93041

1   Cornell Aeronautical
      Laboratory, Inc.
    Avionics Department
    Buffalo, NY 14211
    Attn: Dr. Albert Zavala